Mamal of Surveying
India
1872

its distinguishing name, and the word *District* as the name of that district which is the point required to be seen. The word "Map," prefixing a Title, is generally redundant, but if absolutely necessary in certain cases should not be too conspicuous or in larger letters, but kept subordinate to the name or words most desired to be known; we have endeavoured to exemplify these matters on the pergunnah map of Limbae, Plate X., which is prepared in strict conformity with the standing departmental rules laid down for the guidance of all Surveyors.

The titles, or headings for the village plans, are generally written in a neat round text, *vide* Plate XI. The immense number of these plans, which require to be completed during the season, prevents a more laborious style of printing, and which indeed is not necessary for the description of record; the adjoining names on these latter maps are also recorded in neat round handwriting, as shown on Plate XI. (*See foot-note*, p. 302).

Finishing.

In summing up the several steps before adverted to, it is necessary to make a few remarks on Plan Drawing generally, which may be divided into *Topographical* and *Geographical* maps.

A *Topographical* plan should represent the detail, and contain all that is necessary towards acquiring a special knowledge of a certain extent of ground, or of a small country or district, and especially if for military purposes, for which all plans are more or less intended; such a particular distinction of things and circumstances cannot be attained in geographical maps, which include an extensive portion of the surface of the earth, whole countries and even sometimes the entire globe itself. Topographical maps are made on a larger scale than Geographical ones; *one inch to a mile*, although a small scale for such maps, is a very proper and convenient one, and is the same on which the Ordnance Survey of England is published. It is also the best for the *pergunnah* maps of the Revenue Survey of India, and the smallest scale capable of showing congregated village boundaries in Bengal. *Six inches to one mile* is a large scale for the survey of a county, and is the one employed for the plans of the Ordnance Survey of Ireland. *Two miles to an inch* is a very useful scale for general district maps to show the fiscal and judicial divisions, places of importance, factories, thannahs, &c., forming sheets of moderate size, and convenient for the local authorities to carry about with them when on circuit duty. In the

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hibited, and all such features are now described in pen and ink, horizontal or vertical drawing, for the objects specified in the succeeding chapter.

5TH.—*The district and division maps on the geographical scale, 4 miles = 1 inch, are now compiled in the Surveyor-General's Office.*

CHAPTER XIV.]

North-Western Provinces, this scale is sufficient to show village boundaries, the average area of these circuits being upwards of a square mile, or from 700 to 800 acres each, but in Bengal the villages are so small, averaging not above 300 to 350 acres each, that these boundaries cannot be inserted on this scale. Four miles to an inch is the scale generally used for *geographical* maps, and is well suited for obtaining a general view of an entire country and the relative situation of its parts. The sheets of the great Indian Atlas are prepared on this scale as well as all the *District* compilations from the Revenue Survey Pergunnah maps. By means of maps and plans alone, can a complete practical intimacy with the various parts of a country, and of the face and nature of the ground that composes it, be obtained, and they should therefore afford an accurate view of every local object, and furnish a clear, lively and imposing representation of the reality.

The art of drawing maps and plans consists therefore in representing larger or smaller portions of the surface of the earth on paper, in such a manner that every delineation shall bear as strict a resemblance as possible to the natural object, and the entire skill required is the attainment of a certain facility of manipulation in putting together the materials collected so as to form a map.*

The following remarks "from Jackson's Surveying" may be quoted with advantage:

"A good plan conveys to the mind a more perfect image than can be obtained by looking at the ground itself. It enables us to examine and compare the great features of a country; we trace on it the directions of lines and coasts, rivers, mountains, woods, forests, &c., distance is nothing; we see the country, twenty, fifty and a hundred miles off; we can estimate the comparative heights of hills without having to bear in mind that the angle subtended by a mountain varies with its distance from the eye, or that such an art as perspective exists,—nay more, it may be asserted that a really good plan is fully equal, I had almost said, superior for military purposes to the best model."

"In plans there are three things to be desired; 1st, *correctness*, without which a plan is worse than useless; 2nd, *clearness*, in order that every

* "The object of every map may be stated to be a representation on a flat surface of a portion of the earth, on which all the lines or distances shall, as far as the difference of the surface will permit, bear the same proportion to one another as those in nature do. Accuracy is of course essential to it; but the value of the accuracy is like that of other things, comparative, and is always to be judged of by the cost of its production. Perfect mathematical accuracy is as unattainable as it would be useless, *but that degree of it which is likely to be practically useful, is fortunately within our reach.*"—On the Principles of Geodesy, by Delta, Gleanings in Science, Vol. 2.

part may be understood; 3rdly, *beauty of execution*, which is generally found to accompany the second of these desiderata. This last, however, being the only point upon which the majority of persons are capable, or rather fancy themselves so, of giving an opinion, naturally excites their chief attention."

"When examining a plan how rarely do we think of the labor with which it has been produced, the triangulation to obtain certain points as land marks, the arduous business of surveying every yard of road or stream, the ability and care necessary when sketching the forms of the ground, and the minute attention required for innumerable minor details; how seldom do all or any of these considerations enter into our thoughts when a plan is shown to us; and yet the merit, which attaches to the mere drawing, the language, as it may be termed, of the Surveyor, an accomplishment little more than mechanical, is trifling indeed when compared with the degree of talent and labor employed in the formation of a good plan. Perhaps *time* may afford some criterion whereby to judge of the comparative value of *plan drawing* and *plan making*. An expert draftsman will, in the space of two or three days, produce a copy of a plan, the field labor and plotting of which may have employed a Surveyor for a whole year."

The "practical hints" in the foot-notes, extracted from Simms' Treatise on Drawing Instruments, will be found useful.* We have

* *Practical Hints, &c., on the Management of Drawing Paper.*

The first thing to be done preparatory to the commencement of a drawing, is to stretch the paper evenly upon the smooth and flat surface of a drawing board. The edges of the paper should first be cut straight, and, as nearly as possible, at right angles with each other; also the sheets should be so much larger than the intended drawing and its margin, so as to admit of being afterwards cut from the board, leaving the border by which it is attached thereto by glue or paste, as we shall next explain.

The paper must first be thoroughly and equally damped with a sponge and clean water on the opposite side from that on which the drawing is to be made. When the paper absorbs the water, which may be seen by the wetted side becoming dim, as its surface is viewed slantwise against the light, it is to be laid on the drawing board with the wetted side downwards, and placed so that its edges may be nearly parallel with those of the board; otherwise, in using a T square, an inconvenience may be experienced. This done, lay a straight flat ruler on the paper, with its edge parallel to, and about half an inch from, one of its edges. The ruler must now be held firm, while the said projecting half inch of paper is turned up along its edge; then, a piece of solid glue (common glue will answer the purpose), having its edge partially dissolved by holding it in boiling water for a few seconds, must be passed once or twice along the turned edge of the paper, after which, this glued border must be again laid flat by sliding the rule over it, and, the ruler being pressed down upon it, the edge of the paper will adhere to the board. If sufficient glue has been applied, the ruler may be removed directly, and the edge finally rubbed down by an ivory book-knife, or any clean polished substance at hand, which will then firmly

likewise added a receipt for restoring damaged drawing paper, which in this country so soon becomes affected by the dampness of the atmosphere. Drawing paper should always be wrapped in flannel, and kept closed up in a tin case, and placed well off the ground, and may occasionally be put into an oven and well heated, with advantage.

cement the paper to the board. Another, but adjoining edge of the paper must, next, be acted upon in like manner, and then the remaining edges in succession; we say the adjoining edges, because we have occasionally observed that, when the opposite and parallel edges have been laid down first, without continuing the process progressively round the board, a greater degree of care is required to prevent undulations in the paper as it dries.

Sometimes strong paste is used instead of glue; but, as this takes a longer time to set, it is usual to wet the paper also on the upper surface to within an inch of the paste mark, care being taken not to rub or injure the surface in the process. The wetting of the paper, in either case, is for the purpose of expanding it; and the edges, being fixed to the board in its enlarged state, act as stretchers upon the paper, while it contracts in drying, which it should be allowed to do gradually. All creases or undulations by this means disappear from the surface, and forms a smooth plane to receive the drawing.

Table of Dimensions of Drawing Paper. *Calcutta Price.*

			Rs.	As.
Demy	20 inches by	15½ inches	0	3
Medium	22½ "	17½ "	0	6
Royal	24 "	19½ "	0	8
Super-Royal	27½ "	19½ "	0	8
Imperial	30 "	22 "	0	12
Elephant	28 "	23 "	0	12
Columbier	35 "	23½ "	1	0
Atlas	34 "	26 "	1	0
Double Elephant	40 "	27 "	1	8
Antiquarian	53 "	31 "	4	0
Emperor	68 "	48 "	——	

Mounting Paper and Drawings, Varnishing, &c.

In mounting paper upon canvas, the latter should be well stretched upon a smooth flat surface, being damped for that purpose, and its edges glued down as was recommended in stretching drawing paper. Then, with a brush, spread strong paste upon the canvas, beating it in till the grain of the canvas be all filled up; for this, when dry, will prevent the canvas from shrinking when subsequently removed; and having cut the edges of the paper straight, paste one side of every sheet, and lay them upon the canvas, sheet by sheet, overlapping each other a small quantity. If the drawing paper is strong, it is best to let every sheet lie five or six minutes after the paste is put on it; for, as the paste soaks in, the paper will stretch, and may be better spread smooth upon the canvas; whereas, if it be laid on before the paste has moistened the paper, it will stretch afterwards and rise in blisters when laid upon the canvas. The paper should not be cut off from its extended position till thoroughly dry; and the drying should not be hastened, but gradually take place in a dry room, if time permit; if not, the paper may be exposed to the sun, unless in the winter season, when the help of a fire is necessary, care being had that it is not placed too near a scorching heat.

[PART III.

Comparing and Examining.

All copies of either maps or computations are duly compared with the original by two persons, who affix their initials to the document as having done so, and are strictly responsible for the same. The two copies of the village plans, taken from the rough sheets, are first compared with the original and then with each other, and any discrepancy immediately corrected by an European Assistant and not left for future adjustment, perhaps to be forgotten. The boundary of each village is rigorously compared with the *thakbust* or demarcation sketch map as soon after survey as possible, and it is necessary to record on every map that this step has been taken, and that the assimilation is sufficiently good to allow of its being passed. In case a *khusrah*, or detailed measurement field by field, has been made, the map produced by this operation is also duly compared with the professional one, and the agreement of the two is another proof of

In joining two sheets of paper together, by overlapping, it is necessary, in order to make a neat joint, to feather edge each sheet; this is done by carefully cutting with a knife half-way through the paper near the edges, and on the sides, which are to overlap each other; then strip off a feather-edged slip from each, which being done dexterously, the edges will form a very neat and efficient joint when put together.

The following method of mounting and varnishing drawings or prints was communicated some years ago by Mr. Peacock, an artist of Dublin. Stretch a piece of linen on a frame, to which give a coat of isinglass or common size. Paste the back of the drawing, leave it to soak, and then lay it on the linen. When dry, give it at least four coats of well-made isinglass size, allowing it to dry between each coat. Take Canada balsam, diluted with the best oil of turpentine, and with a clean brush give it a full flowing coat.

In selecting black lead pencils for use it may be remarked that they ought not to be very soft, nor so hard that their traces cannot be easily erased by the India-rubber. Great care should be taken in the pencilling, that an accurate outline be drawn, the pencil marks should be distinct, yet not heavy, and the use of the rubber should be avoided as much as possible, for its frequent application ruffles the surface of the paper, and will destroy the good effect of shading or colouring, if any is afterwards to be applied.

Receipt for restoring damaged Drawing Paper.

Take a wash, composed of one drachm of isinglass steeped in two ounces of water for 12 hours. Then simmer it for 10 or 20 minutes over a fire. When nearly ready add of common alum (fitcooree) in powder twenty grains, strain through linen for use, apply it when the paper is on the drawing board, and damp, and work it on with a flat brush; when dry, wash the paper over with water, which will indicate whether a second wash of the above is necessary. When the paper is thoroughly recovered, wash it well with plain water, and a flat brush, to take off any superfluous isinglass, absorbing the superfluous water with a clean linen rag. When thus prepared, the colors can be thrown in as safely as on good paper.

Captain Henderson's Essay, No. 4, on the Pictorial Art.—*Calcutta Literary Gazette, July*, 1834.

CHAPTER XIV.]

the work, all discrepancies ensuring an immediate enquiry and reconcilement. In like manner all the traverse computations are compared, one Assistant reading from the copy, and the other looking at the original. As soon as these precautions have been taken, and the attesting initials of the Assistants in charge of the division affixed, the document is ready for the examination of the Superintending Officer, who adds his signature as soon as he is perfectly satisfied of the accuracy and sufficiency of the work, and it is by the exercise of his general knowledge and careful eye, in the detection of errors and omissions, that the value of the results of the survey mainly depend. The amount of information embodied in the 1-inch topographical maps from the larger scale requires careful scrutiny, everything should be put in which the scale permits, and these maps forming the chief practical test of a Surveyor's labors as applied to the widest extent of usefulness, no pains should be spared in their examination.

Filling in Village Plan Registers.

The register sheets for the village plans are lithographed and supplied (with a view of lessening the labors of a Surveyor), the statistical and area columns are filled in, the former from the *khusrah* vernacular returns, and the latter from the professional computations as shown in Plates XI. and XI 2. The statistics and general remarks of the condition and state of prosperity of each village are of great importance, and should be recorded by the Surveyor himself. The information thus given, forming the basis of the general statistical and agricultural report of the district. The references to the Settlement Officer's missil, or file of proceedings, enables that Officer to make up his own registers with facility. The duplicate copy of the professional plan register intended for the Civil Authorities is left blank at the back, the numerical data of the survey operations being only required for professional purposes in the Office of the Superintendent of Revenue Surveys. The back of this register being ruled, all the revenue information, as to mehals and proprietors, is inserted on it by the Settlement Officer from the vernacular records of his own proceedings. Every village in the entire district being thus prepared, the detail of information is as complete as can be desired. The following statement represents the form of Register for Bengal, or settled Provinces, the Plan and Traverse computation being recorded precisely similar as shewn in Plate XI. These forms and mode of employing them are now obsolete, the village plan being mapped in clusters on double elephant sheets. The statistical information is recorded in a more condensed form according to Pergunnahs or Tehseels.

[PART III.

Specimen of Village Plan and Register for Settled Districts, Bengal Provinces.

Village of Roypoor. — গ্রাম রায়পুর

Muhal Roypoor. — মহাল রায়পুর

Purgunnah Balleah. — পরগণা বালিয়া

DISTRICT 24-PURGUNNAHS. — জেলা চব্বিষ পরগণা

No. on map.		A.	R.	P.	A.	R.	P.
	Area by Professional Survey				1,387	3	09
	Add Lands of this Village in						
38½	*Chuck Roypoor Tolah* No. 83	12	3	14			
32	*Badee Kaleenuggur* No. 3	26	3	0			
37	*Chuck Nobausan* No 21	9	0	0			
83	*Suntoshbautee* No. 32	14	2	0	63	0	14
	Total Area by Professional Survey				1,450	3	23
	Deduct lands of other villages as detailed below				3	2	0
	Recorded Area of Roypoor ... ... *or Local Beegahs, 4,377.*				1,447	1	23
	Deduct in this Village Lands belonging to						
89	*Nundunpoor*	3	2	0			
	Total to be deducted	3	2	0			

GENERAL REMARKS.

This village has three proprietors and 373 inhabitants, of which 265 are Hindoos and 108 Mussulmen. Five-eighths of the village is cultivated, two-eighths Khanabaree, and one-eighth waste land. There are three qualities of soil, and the average rates per beegah for cultivation are one quarter, one-half, and one respectively, and for Khanabaree, two-tenths.

	A.	R.	P.
Total Area by Khusrah Measurement ... ... *or Local Beegahs, 4,117.*	1,361	0	0

	Ploughs.	Houses. Pucka.	Houses. Kutcha.
Scale {20 *Gunter's Chains* or ¼ *of a Mile*} *to the Inch*	30	6	615

The Local Beegah contains 1,600 Square Yards.	*Surveyed in January 1847.*

No. of Missil or File furnished by Civil Superintendent ...	83	*No. of Mouzas in Civil Superintendent's list* ..	1

Formation of Pergunnah Volumes, &c., &c.

It remains to assort and arrange all the village plans and registers into moderate sized pergunnah volumes, for convenience of record. The plans may be bound up either alphabetically, according to the English or Persian alphabet, or by means of the geographical position of the village. Every plan is duly numbered and placed in regular succession, and from 150 to 200 may be said to form a convenient volume. If a pergunnah is very large, it is of course divided into two or more books as may be necessary; and if very small, two or more pergunnahs are combined together. An alphabetical list of all the villages is prefixed to the volume, containing also columns for the number on the plan as well as the areas, which, summed up, show the correct area of the entire pergunnah. By a reference to this Index List, any plan is immediately found by its number; it is therefore immaterial how the plans are placed, as long as they are numbered properly in succession, and that the index names of villages critically accord with the same on the plan sheets. On opening the book, the plan should first be seen, and then the traverse on the reverse side. A list of topographical references to the coloring is invariably appended, and saves much labor which would accrue from recording such items on every plan. A title page with the name of the pergunnah and a few blank sheets of paper are added, for the purpose of inserting any information afterwards, connected with the Survey operations of the pergunnah or district, or as to the geographical features of the country. On the Revenue Surveys these volumes in fact represent the Field-books, as well as the completed work; they should therefore be made to contain every possible information, and be complete in every respect, so as to supersede the demand for Field-books after a survey is over. So much of the field measurements being recorded on drawing boards, and all plotted at the moment of survey, the Field-books, according to the usual style of that document, are more or less partial and imperfect, and therefore not desirable records.

Division of Labor.

It is next to impossible to lay down absolute and distinct rules for the performance of detail duties. As before stated in Chapter XII., every Deputy Superintendent of Survey may have his own peculiar method of carrying out his work, and in such matters they will be the best judges of the nature of the work they have to perform, and of the best means of completing it; all that we advocate is *system* in all that is done, and whatever that method may be, after it has been once maturely considered and definitely determined on, it should not be departed from. Let a Deputy Superintendent of

Survey apportion out to each Surveyor and assistant the particular duty for which he is most qualified, and insist on its being followed. As a general rule, each Surveyor or Assistant is responsible for the division he has had charge of in the field, and is expected to bring up the whole of the work connected with it; but it frequently happens that from local causes one party may accomplish more field work than they can get out of hand prior to the commencement of another season, whilst another party may not be so pressed for time in the recess; such additional aid and assistance, therefore, as can be spared, should be afforded where it is most needed. Each Surveyor has generally five Sub-Surveyors of various degrees of qualifications under him. One may color well, another may print well, and so on. One man may be employed simply in tracing off, and pencilling in, the village plans. These are made over to a second person to ink in, to a third to be colored, and to a fourth to have station points, letters, and lines entered, and lastly, on to a fifth to write and print adjoining names : such a party can complete from fifteen to twenty village maps daily.

By this arrangement the Surveyor or Assistant Surveyor is enabled to devote himself chiefly to the more important points in finishing the pergunnah or main circuit maps and areas, and the Superintending Officer in exercising a general control over the whole work, taking care that it progresses through every step, to his satisfaction, *methodically*, *cleanly*, and *accurately*; encouraging *and helping* in all difficulties, and by putting the finishing touches to the plans, render them worthy of his professional reputation.

By the means we have here endeavoured to describe, a Deputy Superintendent of Survey may have the satisfaction of seeing his office cleared by the termination of the recess, and find himself in a position to take the field again with renewed vigor, unembarrassed by any arrears.

The following Extract from the "Hand-book of Circular Orders and Instructions of the Revenue Survey Department, India," describes the preparation of Maps for Departmental purposes :—*

(Scale 1 mile = 1 inch.)

Construction of General Maps.

1. The General Maps form the ground-work of the District and Division Map, scale 4 miles = 1 inch, constructed in the Head-Quarter's Office, it is therefore essential that they should be strictly accurate as to village boundaries, with all other geographical details fully exhibited, and, as far as the scale will admit, a perfect reduction of the village plans.

* Compiled from the Departmental orders and instructions of the following Deputy Surveyors-General and Superintendents of Revenue Surveys—Major Bedford, 1832 to 1842; Major Wroughton, 1844 to 1846; Colonel H. L. Thuillier, 1847 to 1865; Colonel J. E. Gastrell, 1865 to 1872; Colonel D. C. Vaurenen, 1867 to 1872.

2. Since the introduction of Photography as a means of reproducing maps, a change become necessary in the style of the preparation of these original records.

Change in the style of drawing for reproduction by Photography.

Continuous maps or sheets filled to margin for the whole district under survey are therefore to be prepared, instead of single isolated main circuit maps.

Sheets or maps filled to margin.

Size of map or sheet.

The size of each such map, or sheet, is to be 20×25 inches.

New topographical symbols, including conventional styles for district, pergunnah, and ordinary village boundaries, have been devised, which shall be substituted for all modes of representing topographical details formerly in use. Sheets of these symbols can be obtained on Indents on the Head-Quarter's Office.

3. The scale should not be entered as "scale *x* mile = *x* inch," but the scale should be drawn and the word "miles" written at the end.

Entry of Scale.

All Maps and Plans shall be drawn in *pen* and *ink*, and no *flat shades* or *coloring* of any kind are to be employed; except in the use of strong carmine (to which a little yellow may be added with advantage) for the *outlines* of metalled roads and masonry buildings, which must not be cross-hatched, but left blank, and of dark *burnt sienna* for the outlines of mud huts in villages, and unmetalled roads, both of which colors are shown as *black* by photography. These outlines, on all large scale plans, must be put in with a mathematical drawing pen to preserve equality of thickness in the strokes; on no account is a common pen, either steel or quill, to be used for this purpose. A very *light blue flat* shade may be used for water which photographs white. Fine lines are on no account to be drawn within the limits of tanks or along streams and rivers. Care must be taken that the ink used for every item is *perfectly black*, and free, when dry, from any metallic lustre. Pale grey ink must on no account be used.

To be drawn in pen and ink.

In representing hills, *brush shading* being totally unsuitable for reproduction by the photographic process, pen and ink work must be introduced. The horizontal touch, after the system delineated in Major Petley's admirable specimens* in Captain Lendy's Book on Military Surveying, which has been circulated to the Department, is the best adapted for this purpose, and is commended to special study and imitation by every Surveyor.

Hills how to be drawn.

The items "lately thrown out of," and "fit for," cultivation are to be omitted on the general maps.

In the reference column the entries of these items will then stand thus:-

Cultivation, including lately thrown out of, and fit for, cultivation.	Blank.

Small plots of barren waste and jungle of less than 40 acres in area are also to be omitted on all mapping on this scale.

4. It is usual to consider the light to come upon a map from the north-west corner, and the shaded side of banks of rivers, tanks, villages, &c., should have a dark line for the sake of effect. In hill shading or contouring, the light is to be considered to fall vertically.

The fall of light.

* Sets, in sheets, of specimens of hill drawing in pen and ink, with blue prints, are prepared in the Surveyor-General's Office for beginners and educational purposes.

5. In sketching ground and in preparing maps it is a rule that a proportionate amount of shade shall be given for a corresponding steepness of slope. But in delineating higher mountains, a darker shade than is due to slope is necessary to make them appear to stand out above the lower hills. Difference in shades is obtained by greater or less closeness of contour lines.

Delineation of the slope of hills.

6. In mapping ground that has been imperfectly surveyed or merely reconnoitred, the representation must be such as to convey a correct impression of the style of the survey, and to distinguish those features which have been loosely delineated from those which have been depicted with strict accuracy. It may be said that a surveyor should abstain from showing anything that cannot be given with fidelity; but this would be still more liable to mislead, as the blanks on a map might be mistaken for unbroken level plains.

Representation of ground imperfectly surveyed.

The necessary distinction shall be conveyed by showing all unsurveyed water-courses by dotted lines, which should indicate the most probable courses of the existing ravines and streams, and will suffice to show that the adjacent hill features are only to be considered to have been approximately delineated.

7. A conventional style of printing names shall be used for all maps in order to show the relative size of Towns and Villages. The scale to be adopted is laid down in Plate 3 of "Conventional Signs." The fine strokes of the printing should not be drawn too fine, or they will be lost in the process of copying by Photography.

Printing of names.

Thannahs, Markets or *Hauts*, Great Trigonometrical Survey Stations, and any places of note shall be shown, as the larger villages, in Roman letters. The scale of 300 houses for the ordinary villages may be considered as equivalent to about 1,000 inhabitants.

8. In the divisions of some Districts, although comprising several hundred square miles of area, possibly there may be no villages containing over 1,000 inhabitants; but in this case, places become important and noted by comparison.

Relative importance of villages to be considered.

9. The names of villages should be entered close to the sites to which they belong, on the right hand side, and due east and west.

Position of names.

10. In preparation of Maps or Plans for reproduction by Photo-zincography, the following procedure is to be invariably observed, *viz.*:—

Procedure to be observed in preparing.

1st.—Enter in pencil all details, of hills as well as streams, with the aid of a tracing glass, or pentagraph.

2nd.—Ink in all rivers, streams, and ravines that do not interfere with names of Villages and Towns.

3rd.—Print names of Villages and Towns.

4th.—Ink in hills and broken ground and such portions of streams, rivers, and ravines as require it after 2nd and 3rd stages. All jungle and detail work must be kept well clear.

11. When hills are covered with forest and bush, a note to that effect must always be inserted on the map. The hill features are never to be obscured by the entry of jungle.

Hill features to be kept clear of jungle.

Names of rivers.

12. The names of rivers should be printed parallel to their courses, and in conspicuous places. When rivers cross the boundary, the name should be written outside the limits of the country mapped.

Names of adjoining Districts, &c.

13. The names of adjoining Districts and Pergunnahs shall be entered on General Maps wherever necessary; the printing of Pergunnah names to be uniform.

14. The names of Tuhseels or Pergunnahs are to be entered with reference to numbers under the border, corresponding numbers being entered on the Maps.

The scale is to be drawn under the border in the centre of the Maps.

Below the border, at the right hand corner, the officer in charge shall attach his own signature.

The designation of the Survey Party shall be given above the margin in the centre of the Map, the No. of the sheet on the left, the name of the District on the right.

Foot-notes.

15. With a view of ensuring strict responsibility, and giving full credit to all parties concerned, foot-notes to maps shall describe precisely the name of every Officer, Assistant, and Native Surveyor, who may have contributed to the execution of the work, and what particular portion of it (both Field and Office) each may have done. The specification, to contain the information as follows, should be neatly printed in one or more lines at foot of the Map:—

The main circuit surveyed by A. B., Assistant Surveyor.

The village boundaries by C. D. and E. F., Sub-Surveyors.

The topographical details by G. H., I. J., and K. L., Sub-Surveyors.

The projection by A. B., Assistant Surveyor.

The drawing by M. N. The Printing by O. P. The comparison and finishing by B. A. The examination by X. Y. (N.B.—The person who draws the Map is never to be entrusted with the examination.)

For the different kinds of Printing to be used in the preparation of General Maps, vide *Topographical items and Specimen Map circulated for guidance.**

Continuation of para. 15.

16. On the general maps, scale 1 mile = 1 inch, the following foot-note is to be inserted in small writing at and beneath the left hand corner of the Map:—

Season 187 -7 . Surveyed, under the superintendence of *(here enter name and rank)*, Superintendent, Revenue Surveys, by *(here name of Officer in charge of party)*, Deputy Superintendent (or Assistant Superintendent in charge), and the following Assistants *(here names of Assistants of Senior and Subordinate Departments)*.

Record of Great Trigonometrical Survey Stations.

17. In all practicable cases, the names of Great Trigonometrical Survey Stations should be recorded, and the difference noted between principal and secondary Stations by adopting the usual symbols for each.

Heights of G. T. Stations.

18. The heights in feet of Great Trigonometrical Survey Stations above sea-level are invariably to be entered on all Maps, in neat red numerals, and are to be taken from the printed Tables of Heights, Great Trigonometrical Survey of India, for Sind, Punjab, North-Western Provinces, and Bengal.

* These can be obtained on Indent from the Hd.-Qr.'s Office.

Heights derived from spirit levelling are to be entered in vertical block numerals to the first place of decimals, thus— ... ... 227·3

Ditto from combination of spirit levelling and triangulation, to the nearest foot only, thus— 214

Preliminary heights obtained from Topographical Survey operations, in sloping italic numerals, thus— *135*

References.

19. The references shall be as full and explicit as possible, so as to render the Maps generally intelligible to non-professional as well as professional persons.

20. In the Table of References the English equivalent should be shown of any local vernacular expressions (such as Khall, Kheong, Dhar, &c., which mean "a stream") which may be employed to designate topographical features.

Station points to be projected.

21. In preparing General Maps, stations at the following points shall be projected, *viz.*, at the junction points of Congregated Village Sheets and on the external boundary of Main Circuits; at the tri-junctions of Districts, Pergunnahs, or Main Circuits; and at all other principal salient and re-entering points on the external boundary. Double circles shall be described for the triple junction stations of Main Circuits; and the stations at which observations for azimuth have been taken shall be marked with a flag.

Roads.

22. Main or metalled roads shall be shown by a double Lake line and common village roads or foot-paths by a single Burnt Sienna line and dots respectively. All roads must be drawn with a mathematical drawing pen to ensure the evenness of the lines, and never with a common quill or steel-pen. The towns from and to which main roads lead shall be invariably recorded.

Rivers.

23. The direction of the stream of rivers shall be shown by an arrow.

Embankments.

24. All *Bunds*, or embankments, shall be shown on all Maps. This information is continually sought for, and is of much importance in Bengal.

Hamlets within a village area.

25. Instances occur of villages of very large area, possessing several different sites, all known by their local names. These *tolahs*, poorwas, or hamlets shall be duly recorded on all Maps as it frequently happens that some of the most widely known places do not, in a revenue sense, constitute a *Mouzah* or separate independent village, and Geographical maps are therefore damaged by their omission; the object of Government is likewise prevented, that the Revenue Survey should afford information on every topographical detail. The word "*tolah*," "poorwah," or "para" need not be repeated on a Map, but the distinguishing appellation of the locality should be inserted in writing rather smaller than that employed for the *uslee* village. The English equivalents for such words "ooroof," Anglice or; "shamil," and "mye" Anglice *with*, *&c.*, shall be entered on Maps, and not the vernacular expressions themselves.

Villages having two names.

26. It likewise frequently happens that the fiscal name of a village, as given in the *Thakbust* list, differs from the *Thannah* name or that by which the village is best known and called by the people of the country; the latter appellation is obviously that which is urgently required

and looked for on a General and Geographical Map. These discrepancies, therefore, should be carefully elicited by Field Surveyors, and noted on the maps by the entry of both names on the Village Maps and the well known name on the General Map.,

Names of Factories, &c.

27. Factories, Salt Golahs, Dâk Bungalows, Temples, Thannahs, Bazars, &c., are not always known by the name of the *uslee* village in which they are situated; their proper designations should be carefully recorded.

Spelling of names.

28. The spelling of fiscal names of villages shall coincide with the Lists furnished by the Settlement Officers, and care must be observed in spelling the same village name in one manner on every Map and record with which it may be connected.

Symbols for recording Magistrate's Offices.

29. The conventional signs for Magistrate's Offices, *Thannahs*, &c., should be entered in the exact positions of the buildings.

Main Streets.

30. Main streets of towns and large villages shall be entered from actual survey.

Type Printing.

31. Whenever type, in place of manuscript or handprinting, is employed for entry of names on General Maps, common printing, or other soft oily ink, must on no account be used; the hardest lithographic ink alone is suitable for the purpose.

The type printing of village names must be perfectly parallel, and in every respect equal, if not superior, to handprinting.

Signatures to Maps.

32. All signatures, both of Surveyors and Assistants, should be neatly and legibly written; a scribbling style of writing is altogether out of place on original and highly finished Maps, and is a great eyesore.

INDEX MAPS (*Scale* 1 *inch* = 4 *miles.*)

Objects of the Map.

1. A Map is required from Surveyors as an index of the season's operations, scale 4 miles = 1 inch, to exhibit the disposition of Main Circuits, to be explanatory of the Annual Report, and to be a guide for the compilation of the District Map.

Projection.

2. On this map all Main Circuit Triple Junction Stations, Great Trigonometrical Survey Stations, the Stations of any series of minor triangulation, and all conspicuous objects met with in the course of survey shall be projected.

Tabular Statement.

3. A Tabular Statement of Co-ordinates shall also be prepared similar to that laid down for General Maps; the successive traverse distances of the exterior points being entered as in an ordinary Traverse Table, and the co-ordinates of all points being referred to the Station of origin.

Topography required.

4. All important geographical features, such as the sites of towns and of the principal villages, rivers, ranges of hills, and main roads, shall be inserted.

When Main Circuits of different Districts are shown on one Map, the names of the Districts shall be entered across the Circuits.

Should be submitted as early as possible.

5. This Map should be transmitted to the Head-Quarters' Office as early as possible during the Recess, in anticipation of the Annual Report and other records.

[PART III.

CONGREGATED VILLAGE PLANS.—*(Scale 4 inches = 1 mile).*

1. The Congregated Village Plans are to be prepared and drawn on imperial paper, and each sheet is to be filled up to margin within the limits of each season's work.

2. To make one unbroken series, it is obvious that sheets containing villages, or portions of villages, belonging to two or more Circuits, must be passed from one Camp to another, to have the villages belonging respectively to each filled in. And the uncompleted sheets of a season must be retained to be filled in after the survey of the omitted portions has been completed.

3. It may occasionally be necessary, when only a small portion of country remains to be mapped on the adjoining sheet, to join on a small fly leaf to complete the Map or Plan, but the system of adding paper must be avoided as much as possible, so as to preserve uniformity in binding the atlas and to ensure greater permanence of record.

How to be ruled in blue.

4. Each sheet is to be carefully ruled with light blue plotting lines, *i.e.*, parallels and perpendiculars to the meridian of origin (100) one hundred chains apart, or (20) twenty squares to each sheet.

Numbers to be given to Villages.

5. Within the boundary of every village a number—the "Survey Number—" is to be given in light blue, by which the village may be readily identified with its Traverse Table, and on the Statistical Return. On the copies of the sheets for the District Authorities the *Thakbust* number will be added, being distinguished by figures in red. Survey numbers must be continuous throughout each District. The last number of each season and each Main Circuit is to be taken up and carried on to the next.

Officers in charge should always arrange with the Settlement Officer that one series of numbers for the District be applied to the *Thakbust* Maps; this series being adopted for the Survey numbers, a double numbering can be avoided, and the same number will be attached to each village on the records of both Surveys.

Numbering of sheets.

6. One series of numbers shall be used for the sheets comprising a District, the numbering passing between sheets geographically contiguous, and being continued through the District from left to right if possible. The names of adjoining Main Circuits of adjoining Districts and Pergunnahs, and the name of every contiguous village, shall be recorded on the outer sheets of Circuits wherever necessary.

Foot-notes and signatures to sheets.

7. Foot-notes shall detail the name of every Assistant and Native Surveyor who may have contributed to the execution of the work of the sheet, the particular portion, both in the Field and Office, each may have performed being specified.

The Officer in charge shall attach his signature at foot of every sheet, after it has been verified and signed by the Assistant in charge of the Camp.

Preparation of Atlas.

8. Each sheet shall bear its own number, the number of Main Circuit, name of District, season of survey, and scale, &c., entered according to the heading of specimen Map A. circulated for guidance. Alphabetical Indices, a copy of Plates Nos. 1, 2, and 3 of Conventional Signs, and Index Map to sheets, shall be prefixed, and the sheets of as many Circuits as may form a convenient Atlas shall be bound up together.

In making out the Alphabetical Index for congregated villages, where the words "Kismust," "Chuck," "Arazee," &c., occur in conjunction with a village name, they are to be inserted AFTER instead of BEFORE the name. The village name will then take its proper place in the Index.

Alphabetical Index.

9. On the Alphabetical Index, the Pergunnah or other territorial subdivision to which each village belongs shall be noted; the lists shall be made up by Main Circuits, and the summation of village areas be shown to correspond (within the percentage of discrepancy allowed) with that of the Main Circuit.

Index Map to sheets.

10. To complete the volume an Index Map to sheets is necessary, a reduced plan on the scale 4 or 2 miles to the inch, to show the sheets as they are relatively situated to each other, their geographical position as sections of the survey of a District, and their relative numbers.

Topography to be inserted.

11. To render these Index Maps more valuable and intelligible guides, a few places of note, with any other topographical details, such as trunk roads, rivers, and ranges of hills, shall be inserted. All information of the names of adjoining Districts, Pergunnahs, and Main Circuits shall be likewise given.

Table of Co-ordinates and Area Statement.

12. A Tabular Statement showing the co-ordinate distances of junction points of sheets from the Station of Origin of the Survey shall be added to the Index Map.

Refers to instructions given for General Maps.

13. The general instructions regarding printing and drawing laid down for General Maps are to be considered equally applicable for Village Plans.

The village boundaries must be ruled in firm black lines.

Sheets of one season to be prepared in a uniform style.

14. Care should be taken that a similarity of style be preserved in the sheets of the different main Circuits of each season's work; uniformity in hill and jungle delineations being indispensable.

Villages having lands detached.

15. If a village be composed of two or more *chucks* or parcels of land, a number shall be given to each, it being of the first importance that the area of every separate demarcation of land should be correctly recorded. *Tuhseel alllidah* lands, or interspersed parcels of one village or *mehal* situated in another, are to be shown in all practicable cases.

Permanent objects near village boundaries.

16. Particular attention should be given to the careful record on Village Plans of all fixed objects on or near the boundaries, by which the latter can be traced and recognised; too much care cannot be observed by the Boundary Assistants in this respect.

Tri-junction pillars how shown.

17. Masonry or stone tri-junction pillars or platforms of villages are also to be shown in Maps wherever they may be found to exist.

Drawing by Natives to be gone over and corrected when necessary.

18. It is expected that all work performed by Native draftsmen be corrected, when glaringly defective or roughly executed.

Original sheets to be sent to Head-Quarters' Office.

19. For some years after the introduction of Congregated Village Sheets, it was the practice to prepare fair copies for submission to the Head-Quarters' Office; this practice is now discontinued, and the original plans first plotted and drawn in field office

or, wherever practical, in the field itself (at time of actual survey) which are more valuable, because more reliable records shall be invariably furnished. Many Surveyors object to furnishing these originals, because they are not clean or neat, but no difficulty should be experienced in their being kept so, it being borne in mind from the first that they are to be permanent records, and even if somewhat soiled, they are most valuable.

Interior or Board Plans to be sent to Head Quarters' Office.

20. All the Interior or Board Plans of each Survey are also to be forwarded to Head-Quarters as soon as intelligence has been received of the safe arrival of the Maps. Each Board Plan is to be marked with corresponding number of the sheet to which it belongs, and signed by the persons immediately and finally responsible for their having been faithfully and truly entered on the records.

Duplicate copies for District Authorities.

21. The Congregated Village Sheets for District Authorities shall have as many complete villages plotted on them as they will conveniently hold, and be drawn with equal care and attention. The Table of co-ordinate distances is to be omitted on the Index Map to sheets and the Station letters are not required on the sheets themselves; in other respects the volumes should be perfectly similar.

Pricking Plans prohibited.

21½. Plans are never to be pricked off. They must invariably be traced, and, when possible, with ink at once.

Objects of Survey to be explained to Zemindars.

22. It is in the highest degree desirable that the people of a District should understand the objects of the Revenue Survey, and take an interest in it; it is also important to circulate copies of the Village Plans. Surveyors shall afford every encouragement and facility to proprietors in this respect explaining to them the advantages they derive from the survey, and supplying them with plans of their estates at a moderate cost.

Rates for copying Village Plans.

23. The following rates are considered a fair remuneration to draftsmen for making copies of a single Village Plans:—

For any Village Plan, not exceeding 1,000 acres	...	Rs.	1	8	0
Ditto, above 1,000 acres	...	„	2	0	0

Eight annas are to be credited to Government for the paper, colors, &c., and the balance paid for the draftsman's labor.

Of Districts already surveyed, and which the Survey Establishment has left, Village Plans will be furnished from the Head-Quarters' Office, at the same rates, on the application of Civil Authorities.

Maps of large *Mehals*, *Pergunnahs*, or Districts do not come under these rates; such documents must be estimated and charged for according to the nature and amount of work.

Plans of towns, cantonments, and forts.

24. A plan on the increased scale of 12 inches= 1 mile (or larger if necessary) is required of all large towns, cities, civil stations, and military cantonments; the environs of important places to the extent of one mile shall also be included. Advantage should be taken of any leisure during the Recess to employ a qualified Assistant for this duty, of making a careful detail survey and laying down every item of information. Besides the limits of cantonments, the boundaries of all lands occupied for military purposes and also the municipal limits of cities and towns must be laid down.

The areas occupied by cantonments, environs, and municipal limits of cities and towns must be recorded on the plans.

All forts and strongholds shall also be surveyed and mapped on the same scale, 12 inches = 1 mile, or larger if required.

To be drawn on Imperial paper.

These plans are to be invariably drawn in sections, filled up to margin, not larger than 27″ × 19″ on paper imperial size (30″ × 22″).

Numbers to be used for references.

References to buildings, roads, and parishes or Mohullas, Tanks, Streams, Temples, Mosques, Gardens, &c., are to be made by numbers in all places where entry of names would interfere with the topography. Names of owners of houses are never to be entered.

The names of subdivisions to be written across the plan.

The names of sub-divisions or quarters of a city or cantonments may be printed across the plan in block, or sans-serif capitals.

Title, References, and Index Map to be entered on outer or separate sheets.

The title and references, together with an Index Map on small scale, showing distribution of the section, are to be entered either on separate sections, or, if necessary, on any convenient blank spaces on the outside sections.

Index Map of Sections.

The Index Map should show only conspicuous objects and principal roads, streams, and sites.

Numbering of Sections.

The Sections are to be numbered from left to right, commencing at the top.

Survey to be minute.

The survey must be as minute as possible, based on minor Triangulation and Traverse Circuits, and all roads should be traversed either by the theodolite and chain, or plane table and perambulator.

STATISTICAL RETURNS.

Change ordered from the old form of Register.

1. When the single village plans were abolished, each of which had as a heading the Statistical Register of the village lands, the same Form of Register was continued, but bound separately, and forming a distinct record, three headings being printed on a half sheet of royal paper.

By Departmental Order No. 2, 11th July 1865, a new form, the "Statistical Return," was substituted for the Register. Being prepared on the same size paper (imperial), these records are to be included in the Atlas with the Congregated Village Plans.

Statistical information.

2. The statistical information required for these Returns, in addition to the details of area, is obtained from the Settlement Department.

Surveyors shall obtain for themselves any useful information regarding forts, remarkable buildings, markets, fairs, &c., which should be entered in the column for "remarks."

SURVEY RECORDS.

Completion of records.

1. The maps and records of each season must be completed during the period of Recess, and it is absolutely required that all should be perfected and reported so before the date when it may be

necessary to take the Field. The time for taking the Field varies according to the climate of the district where a Survey party may be employed.

Records of a previous season not to be taken into the Field.

2. It is not contemplated that any maps or other records should ever remain unfinished at the close of the Recess. Should such an event unfortunately occur (from any cause, which must be fully reported), no records of a previous season shall on any account be taken into the Field; a sufficient number of the establishment must be left behind to complete the work.

Official Records are public property.

3. All official books, maps, and other records, being the property of the State, must be carefully preserved, unless their destruction be sanctioned by proper authority.

Transmission of Records to Head Quarters' Office.

4. On the occasion of transmitting records to be lodged in the Head Quarters' Office, the original board plans and the congregated village sheets prepared from them must never be sent together; the despatch of one set of these records shall be delayed until information be received of the safe arrival of the other. In like manner the field books and the traverse forms shall always be sent separately.

How to be packed.

5. All maps and records are to be transmitted to the Head Quarters' Office, carefully packed in double tin cases, enclosed in an outer case of wood, dammered over, and the transit expenses are to be defrayed by the despatching officer.

CHAPTER XV.

The Application of Photography to the Reproduction of Maps and Plans.

Among the many useful applications of the Art of Photography, one of the most important is the production of absolute facsimiles, on any scale of manuscript drawings and writings.

The advantages that the extension of this principle to the reproduction of maps and plans would afford, were recognised as soon as photography began to be practised as an art, but the first serious attempt to carry it out practically appears to have been made in 1855 by Colonel Sir Henry James, R.E., Director of the Ordnance Survey of Great Britain and Ireland, with the object of obtaining accurate reductions from the large scale surveys, more expeditiously and with more economy, than could be done by means of the pantograph.

The result proved incontestably the great value of photography for this purpose, and its very superior cheapness and rapidity, but for some time its use was limited to obtaining reduced photographic prints for the engravers to trace from on to the copper, and was not extended to multiplying plans for publication, owing to the expense and slowness of production of photographic silver prints, compared with lithographic or copper-plate impressions, and their want of permanence.

The next step appears to have been the endeavour to find some means of obviating the necessity of tracing by hand from these photographs, by transferring the design at once on to the copper plate; and with this object experiments were made with some of the so-called carbon processes, more particularly with Mr. Asser's photolithographic process which had then just been brought to notice; and although this process was not found quite adapted to the purpose intended, the advantages of a method by which facsimile transfers might be made to zinc or stone, and a large number of copies printed off as easily as from an ordinary lithographic drawing, and with the same advantages in respect to cheapness and permanence, were obvious; and in 1860, after many trials, Captain A. deCourcy Scott, R.E., who was in charge of the photographic operations at Southampton, perfected the process of "photozincography, *i.e.*, the production of zincographic impressions by transfer to zinc plates from

photographic transfer-prints in greasy ink, which has since been worked with the greatest success at the Ordnance Survey Office, Southampton, and other public and private institutions in Europe, India, and other parts of the world.

At the same time Mr. W. Osborne, of Melbourne, perfected a similar process of photolithography, which has been extensively used in the Crown Lands Offices of Victoria and Adelaide, for the reproduction of the Maps of the Australian Surveys, and has since been practised commercially on the large scale in Germany and America.

In India, the immense accumulation of Survey results, far beyond the publishing power of the limited establishment of the Lithographic Department of the Surveyor General's Office in Calcutta, and the urgent demand for maps of all kinds consequent on the opening up of the country after the Mutinies, the rapid extension of Railways, Irrigation and other Engineering projects, rendered imperatively necessary the introduction of some means of quickly reproducing and publishing copies of the original Survey Maps as soon as completed. The success that had attended the introduction of the photographic processes in England, for the copying and reduction of maps and plans, attracted the attention of the head of the Survey Department in India, and the services of two trained sappers, with the necessary apparatus, having been obtained from England, a small beginning was made in Calcutta in 1862, and copies vere made of several of the old records, both by the ordinary method of silver-printing and by photolithography, but owing to the difficulties experienced in working the latter process in the peculiar climate of Calcutta, and the fact of all the original maps of the Topographical and Revenue Surveys at that time being coloured and brush shaded, and therefore unsuitable for photographic reproduction, little advance could be made in the practical working of photolithography or photozincography in India till 1865, when Mr. J. B. N. Hennessey, of the Great Trigonometrical Survey, who had in a most praiseworthy spirit devoted part of his furlough in England to going through a practical course of instruction in photozincography at the Ordnance Survey Office, Southampton, brought out with him a complete set of apparatus, and fairly established the photozincographic process in the Office of the Superintendent of the Great Trigonometrical Survey at Dehra Doon. The want of proper supervision at the Head Quarter Office, Calcutta, being much felt, Lieut. J. Waterhouse, R.A., was appointed in 1866 to superintend the photographic operations, and having been trained under Mr. Hennessey at Dehra Doon, took charge of his office at the close of the same year, but shortly afterwards being

obliged by ill-health to proceed to England, the charge devolved upon the late Captain A. B. Melville, under whose energetic supervision and with the aid of additional appliances and the services of two experienced zinc printers from Southampton, the process of photozincography was set fairly working in Calcutta in 1867, and the various difficulties in working it having been gradually recognised and overcome, it has since, under the superintendence of Captain Waterhouse, who relieved Captain Melville on that officer's departure to Europe in 1869, proved of enormous value in quickly and cheaply reproducing the Maps of the Revenue and Topographical Surveys of India, which otherwise could not have been published for years. The process is also largely used for copying plans and drawings of a miscellaneous character, required by various departments of the State.

As the process requires special apparatus and appliances, it cannot advantageously be worked in the small way, and there is, therefore, no necessity for entering closely into details. Those who are interested will find full information as to the practical details in a work on Photozincography by Sir Henry James, and also in a "Report on the Cartographic Applications of Photography" by Lieut. J. Waterhouse, who occupied his furlough in visiting the principal private and public Topographical and Geographical Institutions in England and Central Europe, and has given considerable information on the various methods of photoengraving, photolithography and other processes connected with cartography adopted in these establishments as they existed in 1868, and has, besides, fully described all the manipulations of the photozincographic process, with the trifling modifications found necessary in working it in an Indian climate.

The following brief sketch will give the reader a general idea of the operations in photozincography.

The object of this process is to produce a photographic image in greasy ink, that may be transferred to zinc or stone and printed off in the same manner as an ordinary lithographic transfer drawing.

Though the process has been applied with partial success to the reproduction of subjects in half tones, it is by no means suitable for such work, and is really only applicable to the reproduction of maps and drawings boldly executed in *line* alone.

The success of the operations in copying such maps or drawings depends entirely upon the original drawing being prepared in such a manner that the ground of the photographic negative may be perfectly opaque while the lines are as clear as the bare glass, and in order to secure

the best results the plans should be specially drawn for the purpose in strict accordance with the following rules.

I. The paper on which the drawing is made should be perfectly white and smooth and free from dirt, creases or wrinkles.

II. The drawing should be executed with good Indian ink, freshly rubbed down, *quite black*, and free from grit or glaze.

III. The lines should be firm and clean, not too fine or too close together. They must all be perfectly black, and *pale* ink must on no account be used. Thick lines in the printing and borders should be well filled in.

IV. *Washes* of any colour, except *very pale* blue, are inadmissible, but if necessary, *outlines* of buildings or lines of road, &c., may be drawn in with strong burnt-sienna, burnt-umber, carmine, crimson lake, gamboge and similar colours which will reproduce black. Any detail required to be shown in the original, but not in the copy, may be drawn in with pale cobalt-blue.

V. If cross-hatching or shading is required, the lines composing it must be kept as open and distinct as possible, and they should not be too fine but firm enough to reproduce well. Intensity of shade should be shown by an increase in the thickness of the lines rather than by their being placed close together, as it must be borne in mind that throughout the process there is a tendency for the lines to thicken, so that if they are too close they are liable to block up in the printing, and the work will appear heavy and unsightly. This rule also applies to hill shading, the darker portions of which should be drawn in thick distinct lines, but not crossed and recrossed with fine lines.

VI. River courses, lakes and tanks should be left *blank*, and not filled in with fine lines. If desirable, they may be indicated by a pale wash of blue without detriment to their reproduction.

VII. As the process produces a perfect facsimile of the original, it is essential that the latter should be complete in every respect, and the drawing, printing, and writing should all be done in as neat a style as possible, so that the result may be fit for immediate publication, and not require to be altered or touched up after transfer to zinc, by which the work is always damaged more or less. The hair strokes of the printing must not be too fine.

VIII. When plans are intended for *reduction*, care must be taken to draw the lines of the proper thickness relatively to the scale of reduction: thus, supposing it is required to reduce a drawing to one-fourth the original scale, it will be necessary to draw every line four times as thick as it should appear in the copy. The printing and detail must also be

relatively large in proportion. This rule is often neglected, and the result is the loss of all the finer lines. When drawing for *reduction*, care must be taken to leave sufficient space between the lines of the hill-shading or cross-hatching, so that they may be well separated when reduced, and may not block up in the printing.

IX. When possible, it will be better to draw the original on a larger scale than is required for the copy, as a photographic *reduction* is always much sharper and clearer than a *reproduction*. The scale given in the annexed plate will serve as a guide to show the necessary average thickness of the lines in drawings intended for reduction or reproduction.

X. It is immaterial how the scales on maps for *reproduction* are shown, but in all cases when the copy is to be on a different scale from the original, the scale should be stated merely as a scale of feet, yards, miles, &c., and not as a scale of so many feet, yards, miles, &c., to an inch.

When being copied, the plan must be placed in a good light, and the camera carefully adjusted, so that the plane of the ground glass may be perfectly parallel to the plane of the plan, in order to avoid distortion. The apparatus must be firmly fixed and free from vibration, which would injure the sharpness of the lines. The negative is taken by the usual wet collodion process with iron development, slightly modified in order to secure the greatest transparence in the lines; but as this process will not give sufficient intensity when copying, it is obtained by intensifying the negative, after fixing, in the usual way, then immersing it in a saturated solution of bichloride of mercury till the film becomes white, and finally applying a dilute solution of hydrosulphate of ammonia, which instantly changes the colour of the film to a dark black or brown throughout. The negative is afterwards varnished, and all defects stopped out with Indian-ink or black varnish.

The next operation is to print from this negative a photograph in greasy ink, which may be transferred to zinc or stone. To obtain this, advantage is taken of the property possessed by the alkaline bichromates of rendering gelatine, gum, albumen, and similar organic substances insoluble under the influence of light, and at the same time giving them an affinity for greasy ink; so that, if a sheet of paper be coated with a mixture of gelatine and bichromate of potash, and after it is dry be exposed to light under a negative, then coated evenly with greasy ink and washed with warm water, it will be found that the parts which have been exposed to light retain the ink, while the gelatine on the unexposed parts will dissolve entirely, and be washed away, carrying the superfluous ink with it.

To prepare the sensitive paper, a sheet of bank-post paper is coated in the dark with a mixture of—

Gelatine	...	3 to 5 parts
Bichromate of Potash	...	1 to 3 parts
Water	...	50 parts

and hung up to dry, then coated again and hung up to dry by the other end so as to equalise the coating. When dry the paper is passed through a glazing press to smooth the surface. It is then exposed to light under the negative from one to three minutes in the sun, or until the finest lines are distinctly visible. When sufficiently exposed, which may be ascertained by the whole of the detail appearing in brown upon a bright yellow ground, it is taken out of the printing frame, and passed through a lithographic press in contact with a polished zinc plate, which has been rolled in with thin retransfer ink or lithographic printing-ink, thus receiving an even coating of greasy ink. It is then immersed for a few minutes in a trough of tepid water to soften the gelatine still remaining soluble in those parts which have not been acted upon by light. It is next laid on a sloping glass slab, and washed with a sponge and warm water till all the unaltered gelatine is removed, carrying the superfluous ink with it, while the lines on which the light has acted remain insoluble and retain the ink. When all the details are clearly and sharply defined, and the ground quite free from ink, the print is rinsed with clean water and dried. It is then ready to be transferred to zinc or stone just as an ordinary transfer drawing.

It often happens that a large map or plan must be reproduced in several sections. In this case the transfer prints are carefully joined together with a little gelatine, applied so that it may not be liable to be squeezed out during the process of transfer, and may then be transferred to the zinc plate, or if too large for one plate, cut up into as many convenient-sized sections as necessary.

As zinc plates possess great advantages over lithographic stones on account of their superior lightness, cheapness, facility for storage and infrangibility, they are to be preferred in reproducing plans of large size. The plates used for this purpose are about $\frac{3}{16}$th of an inch in thickness, and have one side carefully planed and smoothed; but in order to give a somewhat porous surface to the plate, so that it may be more absorbent both of moisture and greasy ink, the planed side of the plate is grained by grinding it with very fine sand and water. After the transfers are made, the plate is etched with a preparation of gum and decoction of gallnuts, to which a little phosphoric acid is added. If the transfers are

made to a lithographic stone instead of a zinc plate, the operations are exactly the same as for transferring an ordinary lithographic drawing, except that the stone need not be heated. The operations of printing, whether from zinc or stone, are just the same as in ordinary lithography.

Attention has already been drawn to the necessity for the original drawings being prepared specially to meet the requirements of the process. This was recognised as soon as the photographic process was introduced, but as it involved an entire change in the style of drawing of the maps of the Topographical and Revenue Surveys, it was naturally some time before at all perfect results were obtained; but by sending the surveyors every year, specimens of the reproduction of their work with remarks on the defects, a very high state of excellence has been attained in the preparation of the original maps intended for reproduction by photozincography, so that they now leave little to be desired.

The principal change has been the substitution of pen and ink drawing in black and white, for the old system of brush-shading and high colouring, but though this change is regretted by some and is open to certain drawbacks, there is no doubt that the necessity for drawing the original maps, so that they may be suitable for immediate publication, has effected an immense improvement in the style and finish of these original records, and, although the photozincographed copies appear somewhat rough and coarse, when compared with fine lithographs or engravings, they have the great advantage of being produced quickly and cheaply; and being absolute facsimiles of the original maps submitted by the surveyors, they are entirely free from the errors liable to creep in during the progress of any method of copying a map by hand—of itself an inestimable gain.

The whole of the maps of the Topographical Surveys on the scale of one inch to a mile are now reproduced in this manner immediately after the survey, and an idea may be formed of the great economy in time that is gained by the use of photography for this purpose when it is stated that nearly the whole of the mapping for one season, averaging about 42 sheets, is reproduced and published before the drawing of the maps of the next season's work has commenced.

It is further proposed, in cases where the original maps are susceptible of it, to publish reductions of these sheets on half the scale, combined so as to include half a degree, *i.e.*, one degree of longitude by 30′ of latitude. These sheets will be more convenient for many purposes than the larger scale maps.

A large and increasing proportion of the Revenue Survey maps on the four-inch and one-inch scales are also reproduced by photozincography,

which is rapidly replacing lithography for the purpose with the advantage of an immense gain in time and in accuracy.

The photozincographic process above described is also used at the Office of the Superintendent of the Great Trigonometrical Survey at Dehra Doon for the reproduction of maps and charts connected with that branch of the Survey Department. There is also an establishment of the kind under the Bombay Government at Poona, and another attached to the Revenue Surveys of the Madras Presidency.

When photozincography was first introduced into India, it was hoped that it would be possible by its means to produce the reduced geographical maps on the scale of four miles to one inch direct from the standard maps on the scale of one inch to a mile, but it was soon found quite impossible to make the standard maps serve the double purpose of reproduction and reduction to one-fourth, for in order that they might be legible and clear when reduced, it was necessary that they should be drawn in a much stronger style than was suitable for publication on the larger scale, while at the same time it was necessary to leave out a great deal of detail in order that the reduced map might not be too confused and overcrowded. As it appeared undesirable to make these alterations on the standard one-inch map, a system was introduced of drawing a second map on the same scale, in which the printing and details were exaggerated and generalised, and the whole map drawn in such a style that it might be perfectly clear and distinct when reduced to one-fourth, and only contain the details required on a small-scale map.

This method was a step in advance, but after a few year's experience it was found that the draftsmen had great difficulty in drawing the exaggerated maps and in generalising the hill features and other geographical details in such a manner as to produce satisfactory results when reduced. Another great disadvantage of this system was the small size of the reductions and the necessity of joining eight of them together to make a complete degree sheet, in doing which distortions and other errors arose. It was further found that owing to the standard sheets forming a degree being done in different seasons, and not always by the same draftsman or in the same style, the reductions were wanting in uniformity and unsatisfactory in appearance, requiring a great deal of touching up to make them presentable.

To remedy this, a plan of drawing over *blue* prints, first suggested by Capt. H. C. B. Tanner, of the Revenue Survey, was tried. In order to make up a degree sheet on the four-mile scale in this manner, the original one-mile maps were first of all reduced to one-half; the reductions of the four sheets

forming a half degree were then joined up together, forming a single sheet of double elephant size, transferred to zinc and printed off in light blue, a few copies being also printed in black to serve as guides for the draftsman. These blue prints were then sent to the surveyors to be redrawn in a slightly exaggerated style suitable for reduction to one-half, all details not required on the small-scale map being omitted, and the hill-features so generalized so as to produce a proper effect when reduced to half scale.

This system was found to answer admirably, and although it has since happened that owing to the rapid progress of the engraving of the Atlas of India, the $\frac{1}{4}$-inch degree sheets are no longer required, the method has been usefully applied in making many miscellaneous maps, and will be largely used in preparing the one-inch Revenue Survey maps from the original surveys on the four-inch scale. Its principal advantages are that it is far easier for the draftsman to judge the effect and draw for reduction to one-half than to one-fourth, and as the reduction is only to one-half, any failure in this respect is much less important than when drawing for reduction to one-fourth. The sheets being drawn by a single draftsman are uniform in themselves, and any errors existing between the junctions of the original sheets can be rectified when redrawing. The results are also very fairly accurate to scale, and any differences in this respect can be rectified when making the reduction from the blue print.

The same method has been successfully applied to the production of maps in two colours, and is capable of extensive use. Supposing it is desired to produce a reduced map with the names and outline in black, the hills in neutral-tint, or brown, and the rivers, lakes, &c., in blue. Three blue prints of the original map being taken, the draftsman draws in black upon one the outline and writing, upon the second the hills, and on the third the rivers, &c. These three drawings are then carefully reduced to the same scale and transferred separately to three zinc plates. The first plate is printed in black, the second in neutral-tint or brown, and the third in blue, care being taken to obtain an accurate register by the methods used in ordinary chromo-lithography. If required, more plates and colours can be made in the same way, and if due care is taken the results are very perfect.

It frequently happens that it is required to reduce maps and drawings that, having been drawn in a manner unsuitable for reproduction by photozincography, must be lithographed. In these cases, photography can be very usefully applied in making the reductions and furnishing a trace upon which the lithographic draftsman can make his drawing in the usual manner. Until lately, this was accomplished by making a silver

print of the reduced map over which the draftsmen redrew the work on lithographic tracing-transfer-paper, but the dark colour of the photograph in many cases interfered very much with the drawing. Mr. Fraser S. Crawford, of the Government Photolithographic Office, Adelaide, South Australia, has suggested a method which overcomes this difficulty, and has lately been tried in the Surveyor General's Office, Calcutta, with very beneficial results. The photographic negative having been taken in the usual way, a print is made from it on the paper prepared with bichromate of potash and gelatine as for the ordinary photozincographic process, the only difference being that it must be printed as deeply as possible, so that the lines may remain visible after the bichromate has been washed out. Instead of inking the print, it is simply washed to remove the bichromate, dried and then coated with the ordinary composition used for preparing lithographic transfer-paper. It is then passed through the press to smooth the surface and made over to the draftsman, who has only to ink up the drawing over the faint russet lines of the photographic print. If desirable, an ordinary silver print can be given him as a guide in cases where the bichromate print is not sufficiently distinct for the details to be easily made out.

It has been stated that the photozincographic process is only suitable to the reproduction of subjects in line, and therefore cannot be used for producing copies of coloured or brush-shaded maps or drawings, and until lately, if copies of such maps were required, they could only be produced in small numbers by the ordinary photographic process of silver printing, or if a larger number of copies were wanted, and time was no object, they had to be lithographed or engraved.

Many attempts have, from time to time, been made to overcome the difficulties connected with the reproduction of subjects in half tones by photolithography, but with very partial success, and the problem remained unsolved till the year 1866, when Tessier du Mothay and Maréchal of Metz invented their phototype process, in which a film of hardened gelatine formed the printing surface, from which permanent photographic prints in greasy ink might be printed off in an ordinary lithographic or type printing-press. The process, as at first proposed, possessed the defect of not being capable of yielding a large number of impressions, but was improved upon in this respect by Albert of Munich, and after him by other Germans, and in England by Ernest Edwards of London, with such success that, there are now several methods of permanent printing in this manner, yielding results little inferior in delicacy and beauty to the ordinary silver prints, and capable of furnishing thousands of impressions from a single plate.

The distinctive feature of these processes is that the printing surface is composed of gelatine hardened in such a manner that it may stand the wear and tear of printing, and the principle upon which they depend is very similar to that of photo-transfer printing already described, namely the property possessed by a dried film of gelatine, and similar organic substances mixed with an alkaline bichromate, of becoming insoluble after exposure to light and repelling water in the parts exposed to light exactly in proportion to the amount of the action of light upon them, and of acquiring at the same time an affinity for a greasy substance such as printing ink, so that if a mixture of gelatine, bichromate of potash and some substance that has the property of rendering the gelatine insoluble in water, without rendering it perfectly unabsorbent of water, or interfering with its property of attracting greasy ink in the exposed and repelling it in the unexposed parts, be spread upon a suitable surface and after exposure to light under a photographic negative be washed till all the chromic salt is removed, a printing surface is obtained possessing all the properties of a lithographic stone, that is to say, it is absorbent of water in some parts and of greasy ink in others; but it also has another valuable property which is not possessed by the lithographic stone and has been most aptly termed "a discriminating power of absorption," so that when it is inked with a roller charged with printing ink, the ink will be thickest on the parts representing the deepest shadows of the picture which have received the most exposure to light, the middle tints will take less, the light tints still less, while the high lights will take none at all and be represented by white paper. It will readily be seen that in this way an exact transcript of the original photograph may be obtained, showing the most delicate delineation of detail with as perfect gradation of tone as in an ordinary photograph, but possessing the great superiority of a lithograph, or engraving, over a silver print in respect of undoubted permanence, cheapness, and rapidity of production.

At the same time the process possesses many advantages over lithography and engraving both in the superior delicacy and perfection with which the most minute details can be rendered, and in the great economy caused by the saving of time and skilled manual labour.

For reproductions of subjects in *line* also, the process surpasses most of the known processes of photoengraving, photozincography, or photolithography, in the delicacy, clearness, and sharpness of the results as well as in accuracy of scale, owing to there being no intermediate process of transfer, and the plates being printed by vertical pressure.

[PART III.

It was immediately perceived in India what immense advantages were offered by a process of this kind for cheaply and rapidly producing copies in permanent ink, of photographs for the illustration of Reports and other purposes, and also for extending the advantages of photographic reproduction to such maps and other subjects as could not be dealt with by photozincography, nor in many cases by lithography or engraving on account of the difficulty of procuring skilled lithographic draftsmen and engravers in this country, and the large demand upon the limited staff of these departments of the Calcutta Office. After considerable perseverance in overcoming the difficulties of working such a process in an Indian climate, Capt. Waterhouse has perfected and introduced a photocollotype process analogous to those worked in Europe and yielding equally good results.

The following is an outline of the operations—

As in photozincography, success depends very much on the quality of the negative, and that again on the original. Any negative that will give a good photographic print will answer, but the successful reproduction of maps or shaded drawings demands considerable care in the preparation of the drawing as well as in taking the negative. The precautions already given regarding the preparation of drawings for photozincography are equally applicable to this process, and there is even more necessity, for perfect cleanliness of the paper and neatness and finish of the drawing on account of the tendency of the photocollotype process to reproduce the faintest tints and the almost impossibility of making alterations on the plates, as may be done with engraved copper-plates or drawings on zinc or stone.

Drawings in line may be finer and more delicately executed than for photozincography, but still must not be so fine as to interfere with the obtaining of a perfectly dense and opaque negative, otherwise the ground of the print will appear dirty and stained. Pale ink may be used, if necessary, for effect, but not more than is really requisite.

All kinds of coloured or shaded drawings may also be copied by this process, but the best results can only be obtained from drawings specially prepared for the purpose on smooth paper in monochrome, such as Indian-ink, sepia, neutral tint or similar dark colours.

The negatives of line subjects are intensified and prepared in the same manner as for photozincography, and ordinary negatives of views or copies of coloured drawings give the best results when rather more intense than would be required for silver printing.

As in this process the printing surface receives the image direct from the negative and not by transfer, as in photozincography, it will readily

be understood that the negatives must be *reversed,* which may be in several ways; either by taking the negative through the glass plate instead of on its surface; by using a reversing mirror or prism on the lens; by coating the collodion film with gelatine, and when dry, stripping it off the glass, or by coating it with a solution of India rubber in benzole followed by castor-oil-collodion, and when dry, removing the thin tissue thus formed and laying it down reversed on the same glass plate or better still on to the surface of the printing plate itself.

Unreversed negatives intended for reproduction by this process should not be varnished.

The printing plates are of ordinary thick plate-glass finely ground on one side. Having been thoroughly cleaned, they are carefully levelled and coated with the following composition:—

Gelatine	...	48 parts
Albumen	...	36 „
Glycerine	...	6 „
Distilled water	...	384 „
Tannin	...	1 part

They are then dried in a place free from dust and sensitised in a solution of

Bichromate of Potash	...	1 part
Water	...	20 parts

they are again dried in the dark, and are then ready for use.

The exposure under the negative is performed in the same manner as for ordinary photographs, but if it is desired to secure the sharpest and most perfect results, and the destruction of the negative can be risked, it is better to transfer and reverse the negative film on to the surface of the printing-plate in a bath of spirit of wine, having taken the precaution of covering the gelatine surface with a very slight coating of wax, dissolved in benzole, to enable the negative to be easily removed after exposure.

The exposure varies according to the subject and the intensity of the light from 10 to 15 minutes for a clear line subject in the sun, and from 25 minutes to one hour or longer for a subject in half tones. The proper duration of exposure can be timed very accurately by means of an actinometer containing a graduated scale of intensities corresponding with those of the negatives in general use, under which is placed a glass slip coated with the same composition as the printing-plate and exposed to light at the same time.

hen sufficiently exposed, the negative is removed and the plate is ned round in the frame, so that the *back* surface may be exposed to light from 15 to 30 minutes, in order to thoroughly harden the gelatine and prevent it from swelling too much in the after processes ; it is then taken out of the frame, and the edges having been rubbed with a little tallow, it is plunged into a trough of water and thoroughly washed till all traces of the bichromates are rem; 'ed. After soaking for a few hours the plate is ready for printing.

The printing is performed in an ordinary printing-press, the bed of which is furnished with elastic padding to prevent the plate being broken. For inking in, two lithographic rollers are used, a rough one for laying on the ink, and a smooth one for afterwards removing any superfluous ink and cleaning the ground. A mask is laid on the plate in order to keep the margins clean, and the impression is pulled in the ordinary manner.

The printing of half tone work requires some skill, and in most cases it will be necessary to use two inks, one stiff and dark for the deep shadows, the other softer and lighter for the half shades and lights. The best results are obtained when the prints are made on matt enamelled paper.

Full details of the process and of its adaptability to the requirements of the Survey Department will be found in the Annual Reports of the Topographical Survey and of the Surveyor-General's Department, especially in those for seasons 1871-72 and 1872-73.

[illegible]e are other processes of photo-engraving and photo-relief printing from [illegible]per or zinc, by which excellent copies of maps and drawings may be m[illegible] but as they have no; been brought into general use for that purpo[illegible] and are almost superseded by the new photocollotype processes, it is ne[illegible]ess to do more than mention them and refer the reader for further [illegible]ormation to Captain Waterhouse's Report, already mentioned, and to t[illegible] photographic works treating on these subjects.

CHAPTER XVI.

THE METHOD OF DESCRIBING THE GRATICULE OF MAPS.

FOR the purpose of representing more accurately the globe which we inhabit, geographers have had recourse to spherical balls, on the surface of which are drawn the various divisions of the earth; but the relative divisions of the earth, and the positions of places, cannot be accurately laid down on these spheres, till certain circles have been described on its surface. These circles are divided into *great* and *small*, and the manner in which they are formed may be described as follows. Imagine a sphere to be cut in any direction by a plane, the section will be a circle. It would be a great circle if the cutting plane passed through the centre of the sphere, and a small circle, if it (the cutting plane) passed out of that centre.

From the manner in which a great and small circle are generated, it is evident that the former will bisect the sphere, while the latter will make an unequal division of it.

Of the Axis and Poles.

The earth turns round once in 24 hours, on an imaginary axis, passing through its centre; the two extremities of this axis, are its poles, the one being called the *North* and the other the *South Pole*. This being apprehended, conceive now the terrestrial sphere to be cut by a certain number of planes perpendicular to the rotatory axis, the sections will obviously be parallel to each other; that passing through the centre of the sphere (a great circle) being called the equator, or the equinoctial line, while all the others (small circles) are styled the parallels of latitude, or simply parallels.

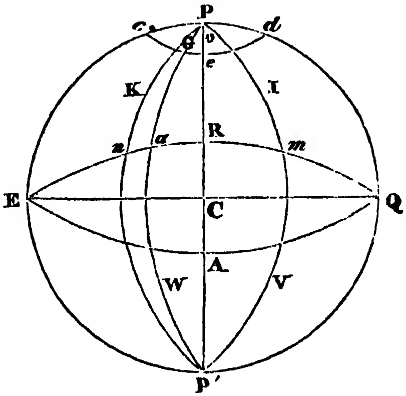
Again, a point being assumed on the terrestrial globe, the cutting plane may be imagined to pass through it, and the axis of rotation, the section (a great circle) will be the meridian of that point, being perpendicular to the equator, and to the parallels, and passing through the North and South Poles.

The latitude and longitude of a place may be defined in the following manner. The meridian to the given place being drawn in the way above described, the section thereof intercepted between the equator and the given point is called the *latitude*, which will be north or south according as the meridional section, which is its measure, extends towards the North or South Pole. The *longitude* is reckoned upon the equator

commencing from a point arbitrarily assumed as the origin, and continued as far as its intersection with the meridian of the given place. In English works on geography the meeting of the equator with the meridian of the Greenwich Observatory, is taken as the origin of the longitudinal arc which is measured both ways, viz., to the east and west of that meridian.

Illustration of Latitude.

"By way of illustrating the foregoing definition of latitude and longitude let us suppose that $PEP'Q$ in adjoining diagram represents the earth, whose axis is PCP'; the North Pole P, and the South Pole P'; and let $EAQR$ represent a circle passing through the centre C, in a direction perpendicular to the axis PP'. This circle corresponds to the equator, and it divides the earth into two hemispheres; EPQ being the Northern, and $EP'Q$ the Southern Hemisphere.



"Let G, I, K represent the situation of three places on the surface of the earth, through which let the great circles PKP', PIP', and PGP' be drawn, intersecting the equator EQ, in n, m, a, respectively.

"These circles are the meridians of the places K, I, G, and as every circle is supposed to be divided into 360°, there must be 90° from the equator to each pole. Hence the latitude of the place K is measured by the degrees of the arc intercepted between K and n; and the latitudes of G and I are measured by the degrees of the arc intercepted between G and a, and I and m, respectively. These latitudes will be called North Latitudes, because the places lie in the Northern Hemisphere.

"In like manner, let there be two places W and V in the Southern Hemisphere. The latitude of W will be measured by the degrees of the arc intercepted between W and a, and the latitude of V, by the arc intercepted between V and m, and these will be called South Latitudes. The distance between I and V is called the difference of latitude.

Illustration of Longitude.

"The longitude of a place is measured by the degrees of an arc of the equator, intercepted between some particular meridian, and the meridian passing through the

place. Thus suppose *G* to represent the particular meridian, an represent the place whose longitude is required; the longitude of *m* measured by the arc *m, a* of the equator, intercepted between *a* and the point where the meridian of *G* meets the equator, and *m* the point of the equator where it is cut by the meridian of the place *m*. The particular meridian, from which we begin to reckon the degrees of longitude, is called the *prime* or *first meridian*, and it is different in different countries.

"In the foregoing diagram if *G* represent the Observatory of Greenwich, *a* will be the point from which we begin to reckon the degrees of longitude: and all places situated to the east of *a*, such as *R, m*, will have East Longitude, while those situated to the west, as *n*, will have West longitude. Longitude is usually reckoned 180° east and west of the prime or first meridian. For instance, taking *a* as the prime meridian and reckoning in the direction *R, m*, Q, we should say, that every place was so many degrees East *Longitude*, while if we reckoned in the direction *n, E*, we should say, all the places had so many degrees West Longitude."* From a consideration of what has been advanced it will be evident that all places situated upon the same meridian have the same *longitude*, while all those situated upon the same parallel have the same *latitude*, again as the parallels of latitude become smaller as they approach the poles, the arcs of these parallels intercepted between the same two meridians will also be smaller as we proceed from the equator to the poles, though in fact they consist of the same absolute number of degrees. Hence it will be easy to see, that a degree of longitude must be smaller towards the poles than at the equator; and must become gradually smaller and smaller till we arrive at the poles, where it will vanish and be equal to nothing.

We have hitherto supposed the earth to be a sphere, but its real figure is a spheroid, the minor axis of which being the axis of rotation. If therefore the several lines whereby latitudes and longitudes are measured, are described upon a spheroid, in the same manner, as has been done upon a sphere, it will be seen that while the equator and the parallels are circles, the meridians are ellipses, equal and similar to one another whose degrees vary in length in different latitudes. The following

* Jamieson's Treatise on Construction of Maps.

Tables exhibit the linear values of the degrees upon the meridian and the parallels from 0° to 46° North Latitude, computed upon the spheroidal hypothesis.

Linear Value in miles of a Degree of Arc measured along the Meridian.						*Linear Value in miles of a Degree of Arc measured along Parallels of Latitude.*					
Mean Latitude.	Meridional Degrees in Miles.	Diff.	Mean Latitude.	Meridional Degrees in Miles.	Diff.	Latitude.	Longitudinal Degrees in Miles.	Diff.	Latitude.	Longitudinal Degrees in Miles.	Diff.
°			°			°			°		
0	68·7027	+	24	68·8160	88	0	69·1618	—	24	63·2171	4789
1	68·7029	2	25	68·8250	90	1	69·1513	105	25	62·7190	4981
2	68·7035	6	26	68·8343	93	2	69·1199	314	26	62·2019	5171
3	68·7045	10	27	68·8439	96	3	69·0676	523	27	61·6658	5361
4	68·7060	15	28	68 8537	98	4	68·9914	732	28	61·1109	5549
5	68·7078	18	29	68·8638	101	5	68·9003	941	29	60·5375	5731
6	68·7101	23	30	68·8740	102	6	68·7854	1149	30	59 9450	5919
7	68·7128	27	31	68·8845	105	7	68·6496	1358	31	59·3365	6101
8	68 7159	31	32	68·8952	107	8	68·4931	1565	32	58·7072	6283
9	68·7194	35	33	68 9061	109	9	68·3158	1773	33	58·0611	6461
10	68·7233	39	34	68·9171	110	10	68·1179	1979	34	57·3973	6638
11	68:7276	43	35	68·9283	112	11	67·8993	2186	35	56·7160	6813
12	68·7322	46	36	68·9397	114	12	67 6601	2392	36	56·0173	6987
13	68·7373	51	37	68·9511	114	13	67·4005	2596	37	55·3015	7158
14	68·7427	54	38	68·9628	117	14	67·1204	2801	38	54·5689	7326
15	68·7485	58	39	68·9745	117	15	66·8200	3004	39	53·8196	7493
16	68·7547	62	40	68·9862	117	16	66·4993	3207	40	53·0538	7658
17	68·7612	65	41	68 9982	120	17	66·1585	3408	41	52·2718	7820
18	68·7680	68	42	69·0101	119	18	65·7976	3609	42	51·4737	7981
19	68 7752	72	43	69·0220	119	19	65 4168	3808	43	50 6600	8137
20	68·7828	76	44	69·0341	121	20	65·0160	4008	44	49·8307	8293
21	68·7906	78	45	69·0461	120	21	64·5956	4204	45	48 9861	8446
22	68·7988	82	46	69·0581	120	22	64·1556	4400	46	48·1265	8596
23	68·8072	84				23	63·6960	4596			

It will not be consistent with the object of the present work to enter into the details on which a map of the world is to be formed, but it will suffice merely to lay down such rules as are absolutely essential for projecting a map of any portion of British India. We cannot, therefore, serve this purpose better than by giving the memorandum of instructions for describing the graticule of maps comprising small portions of the globe, drawn up by the late Col. Blacker, for the use of the Surveyor General's Office, which recommends itself by its remarkable simplicity and accuracy within certain limits. It has long been in use, and is very convenient for mapping, as the topographical details within any one section are easily copied and transferred into any other map differing in projection, or in central meridian. The limits to which it is applicable are confined to about 100 square degrees. The objections to the method are, that it is an empirical process, being based upon no *known projection,* and that the

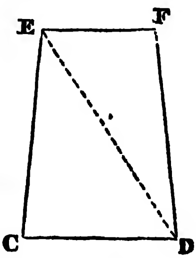
protraction it gives rise to, be it performed with as much care and skill as possible, has always a tendency to generate error, because it is not laid off from one common origin; on the contrary, the spaces are built one on the other, whereby the error in any point is carried on through all the succeeding ones. Where great accuracy is sought for, and the extent of the map is considerable, it becomes necessary to resort to the principles of conical development, and to protract by means of co-ordinates and a common origin. For this purpose some new Tables have been introduced by the late Surveyor-General of India, whereby, by means of rectangular co-ordinates from a common origin, the parallels and meridians may be projected to every degree, and to every 2° according to the scale; but these Tables are too extensive for insertion in this work.

Col. Blacker's memorandum.

"The following method of delineating the meridians and parallels of a map, although not solely referrible to any of the demonstrated projections, evidently contains so much truth, as to be well adapted to topographical plans embracing a very small portion of the hemisphere.

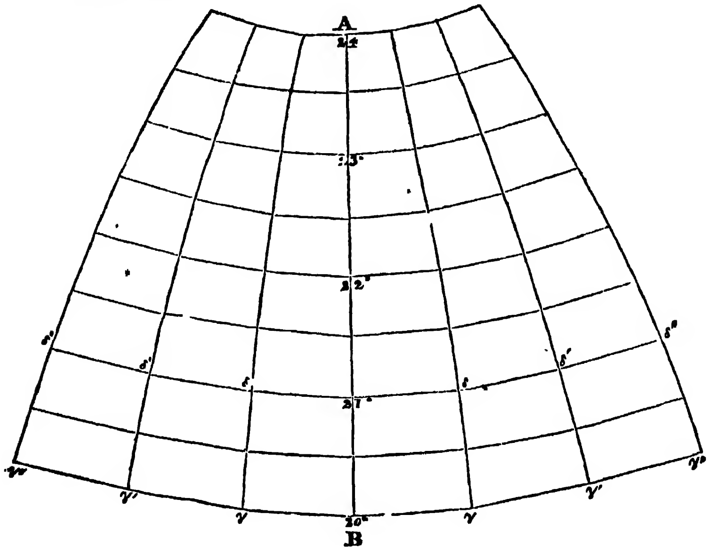
"By a mechanical operation, so simple as to require but little explanation, is produced a graticule, whose meridians are all equal, are equidistant at all the corresponding points, are intersected by the parallels at equal angles on the same side; and whose parallels consist of parts proportional to the cosines of their latitude.

"These properties will be rendered more obvious by the detailed account of a construction adapted to an assumed case; such, for example, as the delineation of a graticule comprising 4 degrees of latitude, between the parallels of 20° and 24°, and as many of longitude, on a scale of 4 miles to an inch.



"Let there be imagined a quadrilateral *CEFD*, whose sides shall each be equal to a degree on the meridian, and whose bases shall be equal to half degrees of longitude at the latitudes in which they may be situate; the angles *E* and *F* being equal, as likewise *C* and *D*, it is obvious that the comprised area will represent a portion of the earth's surface, one degree of latitude high, and half a degree of longitude broad; and that it may be transferred to any given line, either by determining one angle of the equilateral or its diagonal *ED*. Let the latter quantity be preferred, since it will be always more correct to lay

a line, than to protract an angle; and suppose the diagonal to ve been ascertained.

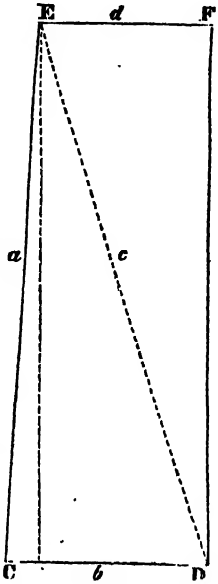


"Let a straight line AB for the central meridian divide the paper from top to bottom; and at the lower part thereof, lay off the distance 21—20° = CE. From the point 20° describe on each side of the central meridian, an arc with the radius CD = half a degree of longitude in latitude 20°. Describe similar arcs from the point 21° with the radius EF = half a degree longitude at latitude 21°. Intersect the two first from 21° with the diagonal distance ED, and the two last from 20° with the same distance. These several intersections, λ δ, will obviously be points correspondent to D, F, and may be joined accordingly to the other points.

"If a similar construction be repeated by applying the same quadrilateral to the new sides δ, a fresh set of points, γ' δ', will be obtained, and will supply the means of continuing the operation still further.

"Two series of points, 20° γ'' and 21° δ, δ', δ', will be thus generated at the distance of a degree of latitude from each other. They may be connected in the direction 21° δ, &c., and 20° γ, &c., by which means will be described two parallel lines of sensible curvature: and again joined in the directions γ δ, γ' δ', γ'' δ'', &c., which will form parts of different meridians half a degree asunder. As it is usual on a scale of 4 miles to an inch to draw parallels at every 30 minutes' distance, the last mentioned

meridional parts may be bisected, and the points of bisection con: for a new parallel. If similar constructions be extended to the right a left of the intervals 22°—21°, 23°—22°, 24°—23°, it is evident that the graticule will be complete, and have all the properties claimed for this method as far as is consistent with graphical means.



"The convergency of the meridians will, however, not be sensible near the central line of the paper; but perhaps there is no other so simple method of delineating them, even as right lines, and at the same time indicating all their intersections with the parallels of latitude.

"It remains now to be seen how the diagonal *ED*, which has been assumed as known, shall be obtained; and for this purpose let a line be imagined parallel to *FD* from the point *E*. It will evidently be one side of an isosceles triangle whose base is $= CD - EF$, and whose remaining side is $CE = FD$.

"Denoting, therefore, the side *CE* by a, *CD* by b, *EF* by d, and the diagonal *ED* by c, we have in the isosceles triangle, $\text{Cos } C = \frac{b-d}{2a}$, and in the oblique-angled triangle *DCE* .... $c^2 = a^2 + b^2 - 2ab \text{ Cos } C =$ (by substituting the value of Cos *C* already found), $a^2 + b^2 - 2ab\,\frac{b-d}{2a} = a^2 + b^2 - b^2 + bd = a^2 - bd = a^2\left(1 + \frac{bd}{a^2}\right)$, and therefore $C = \sqrt{a^2\left(1 + \frac{bd}{a^2}\right)} = a\sqrt{1 + \frac{bd}{a^2}}$

Type of the Calculation.

a = 60532 fathoms, b = 28604·5 fathoms, d = 28419·5 fathoms.

log. b = 4·45643   log. a = 4·78198
log. d = 4·45362
Ar. com. log. a = 5·21802
idem = 5·21802

log. $\frac{bd}{a^2}$ = 9,34609

$1 + \frac{bd}{a^2}$ = 1·22187

log. do. = 0·08702 whose square root = 0·04351

log. c = 4·82549 = 66910 fathoms.

"In like manner may the diagonals of the remaining quadrilaterals be determined; and when reduced, with the other parts, to the scale of the map, will give at once, in inches, the sides a, b, d, and diagonal c for every latitude.

"In the present supposition the ratio of the scale is $\frac{1}{253440}$; by which, therefore, dividing the foregoing quantities, we shall have

$$a = 17.20 \text{ inches}$$
$$b = 8.13 \quad ,,$$
$$d = 8.07 \quad ,,$$
$$c = 19.01 \quad ,,$$

"If so far has been thoroughly understood, there will be no difficulty in using the following Tables, which give the parts of every quadrilateral of one latitudinal degree high, and half a longitudinal degree broad, between the parallels of 5° and 36° for the larger scales and 4° to 46° for the smaller.*

"But the scale of 4 miles to 1 inch is not the only ratio which may be required; and therefore other sets of Tables are added for the scale of 8 miles, and of its several multiples by 2, 3, 4 and 6 to 1 inch, also those for 1 mile and 12 miles to the inch, to complete the set.

"As the scale decreases, however, it will be proper that the number of degrees contained in the sides and bases of the quadrilateral should increase. The following law will, therefore, be observed, which is calculated to maintain always a regular curvature, without marking by too sensible an angle the junction of one quadrilateral with another.

Nos.	*Scale of Miles to 1 Inch.*	*Ratio of Scale.*	*Degrees in a.*	*Degrees in b and d.*	
I	4	$\frac{1}{253440}$	1°	0°, 30′	† Divide a by 2
II	8	$\frac{1}{506880}$	2°	1,	
III	16	$\frac{1}{1013760}$	3°	1,	† Divide a by 3
IV	24	$\frac{1}{1520640}$	3°	1,	
V	32	$\frac{1}{2027520}$	4°	2,	† Divide a by 2
VI	48	$\frac{1}{3041280}$	4°	2,	

* Taken from the revised "Auxiliary Tables" for the use of the Survey Department, published by Lieut.-Col. J. T. Walker, R.E., Superintendent, Great Trigonometrical Survey, 1868.

† NOTE.—The divisions, here directed, have for object the reduction of the quadrilaterals to the areas proposed to be comprized in the graticule. Thus, in the 1st scale, there will be an intersection at every half degree; in the 2nd, 3rd and 4th, at every degree; and in the 5th and 6th at every second degree.

CHAPTER XVI.]

Sides of Squares of $\frac{1}{4}$° of Latitude and Longitude, with the Diagon thereof on the scale of 1 mile to 1 inch.

a represents the Distance on the Meridian.
b „ „ on the Lower parallel of Latitude.
d „ „ on the Upper parallel of „
c „ the Diagonal of the Square.

Latitude. ° ′ ° ′	*a* in Ins.	*b* in Ins.	*d* in Ins.	*c* in Ins.	Latitude. ° ′ ° ′	*a* in Ins.	*b* in Ins.	*d* in Ins.	*c* in Ins.
From 5 0 to 5 15	17·177	17·225	17·218	24·323	From 20 30 to 20 45	17·197	16·202	16·176	23·618
5 15 „ 5 30	·177	·218	·211	·318	20 45 „ 21 0	·197	·176	·149	·600
5 30 „ 5 45	·177	·211	·204	·314	21 0 21 15	·198	·149	·122	·582
5 45 „ 6 0	·177	·204	·196	·308	21 15 21 30	·198	·122	·095	·564
6 0 „ 6 15	·178	·196	·188	·303	21 30 21 45	·199	·095	·067	·546
6 15 „ 6 30	·178	·188	·180	·298	21 45 22 0	·199	·067	·039	·527
6 30 „ 6 45	·178	·180	·171	·292	22 0 22 15	·200	·039	011	·508
6 45 „ 7 0	·178	·171	·162	·285	22 15 22 30	·201	011	15 982	·490
7 0 „ 7 15	·178	·162	·153	·279	22 30 22 45	·201	15·982	·953	·470
7 15 „ 7 30	·179	·153	·143	·273	22 45 „ 23 0	·202	·953	·924	·451
7 30 „ 7 45	·179	·143	·134	·266	23 0 „ 23 15	·202	·924	·895	·431
7 45 „ 8 0	·179	·134	·123	·259	23 15 „ 23 30	·203	·895	·865	·412
8 0 „ 8 15	·179	·123	·113	·252	23 30 „ 23 45	·203	·865	·835	·392
8 15 „ 8 30	·179	·113	·102	·244	23 45 „ 24 0	·204	835	·804	·372
8 30 „ 8 45	·180	·102	·091	·237	24 0 „ 24 15	·204	·804	·774	·351
8 45 „ 9 0	·180	·091	·079	·229	24 15 „ 24 30	·205	·774	·743	·331
9 0 „ 9 15	·180	·079	·067	·221	24 30 „ 24 45	·205	·743	·711	·310
9 15 „ 9 30	·180	·067	·055	·212	24 45 25 0	·206	·711	·680	·289
9 30 „ 9 45	·180	·055	·042	204	25 0 25 15	207	680	·648	·269
9 45 „ 10 0	·181	·042	·029	·195	25 15 25 30	·207	·648	616	·247
10 0 „ 10 15	·181	·029	·016	·186	25 30 25 45	·208	·616	·583	·226
10 15 „ 10 30	·181	·016	·003	·177	25 45 26 0	·208	·583	·550	204
10 30 „ 10 45	·182	003	16·989	·168	26 0 26 15	·209	·550	·517	·183
10 45 „ 11 0	·182	16·989	·975	·159	26 15 26 30	·209	·517	·484	·161
11 0 „ 11 15	·182	·975	·960	·148	26 30 „ 26 45	·210	·484	·450	·139
11 15 „ 11 30	·182	·960	·916	·138	26 45 „ 27 0	·211	·450	·416	·117
11 30 „ 11 45	·183	·946	·930	128	27 0 27 15	·211	·416	382	·094
11 45 „ 12 0	·183	·930	·915	·118	27 15 27 30	·212	·382	·348	·072
12 0 „ 12 15	·183	·915	·899	·107	27 30 „ 27 45	·213	·348	·313	·050
12 15 „ 12 30	·184	·899	·883	097	27 45 „ 28 0	·213	·313	·278	·027
12 30 „ 12 45	·184	·883	·867	·085	28 0 „ 28 15	·214	·278	·242	·004
12 45 „ 13 0	·184	·867	16·850	·073	28 15 28 30	·214	·242	·207	22 981
13 0 „ 13 15	·185	·850	·833	·062	28 30 „ 28 45	·215	207	·171	958
13 15 „ 13 30	·185	·833	·816	050	28 45 29 0	216	·171	·134	·934
13 30 „ 13 45	·185	·816	·798	·037	29 0 29 15	·216	·134	·093	·910
13 45 „ 14 0	·186	·798	·780	·026	25 15 29 30	217	·098	061	·887
14 0 „ 14 15	·186	·780	·762	·013	29 30 „ 29 45	·218	·061	·024	·863
14 15 „ 14 30	·186	·762	·743	·000	29 45 30 0	·218	·024	14·986	·839
14 30 „ 14 45	·187	·743	·724	23·988	30 0 30 15	219	14 986	·949	·815
14 45 „ 15 0	·187	·724	·705	974	30 15 30 30	219	·949	·911	·790
15 0 „ 15 15	·187	·705	·685	·961	30 30 30 45	220	·911	·872	·766
15 15 „ 15 30	·188	·685	·666	·948	30 45 31 0	221	·872	·834	·741
15 30 „ 15 45	·188	·666	·645	·934	31 0 31 15	221	·834	·795	·716
15 45 „ 16 0	·188	·645	·625	·920	31 15 31 30	·222	·795	·756	·692
16 0 „ 16 15	·189	·625	·604	·906	31 30 31 45	·223	·756	.716	·667
16 15 „ 16 30	·189	·604	·583	·892	31 45 32 0	·223	·716	·677	·641
16 30 „ 16 45	·190	·583	·561	·877	32 0 32 15	·224	·677	·637	·616
16 45 „ 17 0	·190	·561	·540	·862	32 15 32 30	·225	·637	·597	·591
17 0 „ 17 15	·191	·540	·518	·848	32 30 32 45	·226	·597	·556	·566
17 15 „ 17 30	·191	·518	·495	833	32 45 33 0	·226	·556	·515	·539
17 30 „ 17 45	·191	·495	·472	·817	33 0 33 15	·227	·515	·474	·514
17 45 „ 18 0	·192	·472	·449	·801	33 15 33 30	·228	·474	·433	·488
18 0 „ 18 15	·192	·449	·426	·786	33 30 33 45	·228	·433	·391	·461
18 15 „ 18 30	·193	·426	·402	·770	33 45 34 0	·229	·391	·349	·435
18 30 „ 18 45	·193	·402	·378	·754	34 0 34 15	230	·349	·307	·409
18 45 „ 19 0	·194	·378	·354	·738	34 15 34 30	·230	·307	·265	·382
19 0 „ 19 15	·194	·354	·330	·721	34 30 34 45	·231	·265	·222	·356
19 15 „ 19 30	·195	·330	·305	·705	34 45 35 0	·232	·222	·179	·329
19 30 „ 19 45	·195	·305	280	·688	35 0 35 15	·232	·179	·136	·302
19 45 „ 20 0	·195	·280	·254	·670	35 15 35 30	·233	·136	·092	·275
20 0 „ 20 15	·196	·254	·228	·653	35 30 35 45	·234	·092	·048	·248
20 15 „ 20 30	·196	·228	·202	·635	35 45 36 0	·235	·048	·004	·221

Sides of Squares of ½° of Latitude and Longitude, with the Diagonals thereof, on the scale of 4 miles to 1 inch.

Latitude.	a in Ins.	b in Ins.	d in Ins.	c in Ins.	Latitude.	a in Ins.	b in Ins.	d in Ins.	c in Ins.
° ′ ° ′					° ′ ° ′				
From					From				
5 0 to 5 30	8·589	8·613	8·606	12·161	20 30 to 21 0	8·599	8·101	8·074	11·805
5 30 ,, 6 0	·589	·606	·598	·156	21 0 ,, 21 30	·599	·074	·047	·786
6 0 ,, 6 30	·589	·598	·590	·150	21 30 ,, 22 0	·600	·047	·019	·768
6 30 ,, 7 0	·589	·590	·581	·144	22 0 ,, 22 30	·600	·019	7·991	·749
7 0 ,, 7 30	·589	·581	·572	·138	22 30 ,, 23 0	·601	7·991	·962	·730
7 30 ,, 8 0	·589	·572	·562	·131	23 0 ,, 23 30	·601	·962	·932	·711
8 0 ,, 30	·590	·562	·551	·124	23 30 ,, 24 0	·602	·932	·902	·691
8 30 ,, 9 0	·590	·551	·539	·116	24 0 ,, 24 30	·602	·902	·871	·670
9 0 ,, 9 30	·590	·539	·527	·108	24 30 ,, 25 0	·603	·871	·840	·650
9 30 ,, 10 0	·590	·527	·515	·100	25 0 ,, 25 30	·603	·840	·808	·629
10 0 ,, 10 30	·591	·515	·501	·091	25 30 ,, 26 0	·604	·808	·775	·608
10 30 ,, 11 0	·591	·501	·487	·081	26 0 ,, 26 30	·605	·775	·742	·586
11 0 ,, 11 30	·591	·487	·473	·071	26 30 ,, 27 0	·605	·742	·708	·564
11 30 , 12 0	·591	·473	·458	·061	27 0 ,, 27 30	·606	·708	·674	·542
12 0 , 12 30	·592	·458	·442	·050	27 30 ,, 28 0	·606	·674	·639	·519
12 30 , 13 0	·592	·442	·425	·039	28 0 ,, 28 30	·607	·639	·603	·496
13 0 , 13 30	·592	·425	·408	·028	28 30 ,, 29 0	·608	·603	·567	·473
13 30 ,, 14 0	·593	·408	·390	·016	29 0 ,, 29 30	·608	·567	·530	·449
14 0 ,, 14 30	·593	·390	·372	·003	29 30 ,, 30 0	·609	·530	·493	·425
14 30 , 15 0	·593	·372	·353	11·990	30 0 ,, 30 30	·610	·493	·455	·401
15 0 , 15 30	·594	·353	·333	·977	30 30 ,, 31 0	·610	·455	·417	·377
15 30 , 16 0	·594	·333	·312	·963	31 0 ,, 31 30	·611	·417	·378	·352
16 0 , 16 30	·595	·312	·291	·949	31 30 ,, 32 0	·612	·378	·388	·3[illegible]7
16 30 ,, 17 0	·595	·291	270	·935	32 0 ,, 32 30	·612	·338	·298	·302
17 0 , 17 30	·595	·270	·248	·920	32 30 ,, 33 0	·613	·298	·258	·276
17 30 , 18 0	·596	·248	·225	·905	33 0 ,, 33 30	·614	·258	·216	·250
18 0 , 18 30	·596	·225	·201	·889	33 30 ,, 34 0	·614	·216	·175	·224
18 30 , 19 0	·597	·201	·177	·873	34 0 ,, 34 30	·615	·175	·132	·198
19 0 , 19 30	·597	·177	·152	·856	34 30 ,, 35 0	·616	·132	·090	·171
19 30 , 20 0	·598	·152	·127	·840	35 0 ,, 35 30	·616	·090	·046	·144
20 0 , 20 30	·598	·127	·101	·822	35 30 ,, 36 0	·617	·046	·002	·117

Sides of Squares of 1° of Latitude and Longitude, with the Diagonals thereof, on the scale of 8 miles to 1 inch.

Latitude.	a in Ins.	b in Ins.	d in Ins.	c in Ins.	Latitude.	a in Ins	b in Ins.	d in Ins.	c in Ins.
° °					° °				
From					From				
5 to 6	8·589	8·613	8·598	12·158	21 to 22	8·899	8·074	8·019	[illegible]1·777
6 ,, 7	·589	·598	·581	·147	22 ,, 23	·600	·019	7·962	·740
7 ,, 8	·589	·581	·562	·134	23 ,, 24	·601	7·962	·902	701
8 ,, 9	·590	·562	·539	·120	24 ,, 25	·603	902	·840	·660
9 ,, 10	·590	·539	·515	·104	25 ,, 26	·604	·840	·775	·618
10 ,, 11	·591	·515	·497	·086	26 ,, 27	·605	·775	·708	·575
11 ,, 12	·591	·487	·458	·066	27 ,, 28	·606	·708	·639	530
12 ,, 13	·592	·458	·425	·045	28 ,, 29	·607	·639	·567	·484
13 ,, 14	·593	·425	·390	·022	29 ,, 30	609	·567	·493	·437
14 ,, 15	·593	·390	·353	11·997	30 ,, 31	·610	·493	·417	·389
15 ,, 16	·594	·353	·312	·970	31 ,, 32	·611	·417	·338	·339
16 ,, 17	·595	·312	·270	·942	32 ,, 33	·613	·333	·258	·289
17 ,, 18	·596	·270	·225	·912	33 ,, 34	·614	·258	·175	·237
18 ,, 19	·596	·225	·177	·881	34 ,, 35	·615	·175	·090	·184
19 ,, 20	·597	·177	·127	·848	35 ,, 36	·617	·090	·002	·131
20 ,, 21	·598	·127	·074	·813					

Sides of Squares of 2° of Latitude and Longitude, with the Diagonals thereof, on the scale of 12 miles to 1 inch.

Latitude ° ° From	*a* in Ins.	*b* in Ins.	*d* in Ins.	*c* in Ins.	Latitude ° ° From	*a* in Ins.	*b* in Ins	*d* in Ins.	*c* in Ins.
4 to 6	11·451	11·499	11·464	16·216	26 to 28	11·474	10·367	10·185	15·403
6 „ 8	·452	·464	·416	·187	28 „ 30	·477	·185	9·991	·280
8 „ 10	·453	416	·353	·149	30 „ 32	·481	9 991	·785	·151
10 „ 12	·455	353	·277	·101	32 „ 34	·484	·785	·566	·016
12 „ 14	·456	·277	·187	·044	34 „ 36	·488	·566	·336	14·876
14 „ 16	·458	·187	·083	15·977	36 „ 38	·492	·336	·095	·730
16 „ 18	·460	·083	10 966	·902	38 „ 40	·496	·095	8 842	·580
18 „ 20	·463	10 966	·836	·818	40 „ 42	·500	8·842	·579	·426
20 „ 22	·465	·836	·693	·726	42 „ 44	·504	·579	·305	·268
22 „ 24	·468	·693	·536	·626	44 „ 46	·508	·305	·021	·108
24 „ 26	·471	·536	·367	·518					

Sides of Squares of 2° of Latitude and Longitude, with the Diagonals thereof, on the scale of 16 miles to 1 inch.

Latitude. ° ° From	*a* in Ins	*b* in Ins.	*d* in Ins.	*c* in Ins.	Latitude. ° ° From	*a* in Ins.	*b* in Ins.	*d* in Ins	*c* in Ins.
4 to 6	8·588	8 624	8·598	12·162	26 to 28	8·606	7·775	7·639	11·552
6 „ 8	·589	·598	·562	·140	28 „ 30	·608	·639	·493	·460
8 „ 10	·590	·562	·515	·111	30 „ 32	·611	·493	·338	·364
10 „ 12	·591	·515	·458	·076	32 „ 34	·613	·338	·175	·262
12 „ 14	·592	·458	·390	·033	34 „ 36	·616	·176	·002	·157
14 „ 16	·594	·390	·312	11·983	36 „ 38	·619	·002	6·821	·048
16 „ 18	·595	·312	·225	·927	38 „ 40	·622	6·821	·632	10·935
18 „ 20	·597	·225	·127	·864	40 „ 42	·625	·632	·434	·819
20 „ 22	·599	·127	019	·795	42 „ 44	·628	·434	·229	·701
22 „ 24	·601	·019	7·902	·720	44 „ 46	·631	·229	·016	·581
24 „ 26	·603	7·902	·775	·639					

Sides of Squares of 2° of Latitude and Longitude, with the Diagonals thereof, on the scale of 24 miles to 1 inch.

Latitude. ° ° From	*a* in Ins.	*b* in Ins.	*d* in Ins.	*c* in Ins.	Latitude. ° ° From	*a* in Ins.	*b* in Ins.	*d* in Ins.	*c* in Ins.
4 to 6	5·726	5·750	5·732	8·108	26 to 28	5·737	5·188	5·093	7·701
6 „ 8	·726	·732	·708	·094	28 „ 30	·739	·093	4·995	·640
8 „ 10	·727	·708	·676	·074	30 „ 32	·740	4·995	·892	·576
10 „ 12	·727	·676	·638	·050	32 „ 34	·742	·892	·783	·508
12 „ 14	·728	·638	·593	·022	34 „ 36	·744	·783	·668	·438
14 „ 16	·729	·593	·542	7·989	36 „ 38	·746	·668	·547	·365
16 „ 18	·730	·542	·483	·951	38 „ 40	·748	·547	·421	·290
18 „ 20	·731	·483	·418	·909	40 „ 42	·750	·421	·289	·212
20 „ 22	·733	·418	·346	·863	42 „ 44	·752	·289	·153	·134
22 „ 24	·734	·346	·268	·813	44 „ 46	·754	·153	·011	·054
24 „ 26	·735	·268	·183	·759					

Sides of Squares of 2° of Latitude and Longitude, with the Diagonals thereof, on the scale of 32 miles to 1 inch.

Latitude. ° °	*a* in Ins.	*b* in Ins.	*d* in Ins.	*c* in Ins.	Latitude. ° °	*a* in Ins.	*b* in Ins.	*d* in Ins.	*c* in Ins.
From					From				
4 to 6	4·294	4·312	4·299	6·081	26 to 28	4·303	3·888	3·819	5·776
6 ,, 8	·295	·299	·281	·071	28 ,, 30	·304	819	·747	·730
8 ,, 10	·295	281	·257	·056	30 ,, 32	·305	747	·669	·682
10 ,, 12	·295	·257	·229	·038	32 ,, 34	·307	669	·587	·631
12 ,, 14	·296	·229	·195	·016	34 ,, 36	·308	·587	·501	·578
14 ,, 16	·297	·195	·156	5·991	36 ,, 38	·309	501	·411	·524
16 ,, 18	·298	·156	·112	·963	38 ,, 40	·311	·411	·316	·467
18 ,, 20	·298	·112	·064	·932	40 ,, 42	·312	·316	·217	·410
20 ,, 22	·299	·064	·010	·897	42 ,, 44	·314	·217	·114	·351
22 ,, 24	·300	·010	3·951	·860	44 ,, 46	·315	·114	·008	·291
24 ,, 26	·302	3·951	·888	·819					

Sides of Squares of 2° of Latitude and Longitude, with the Diagonals thereof, on the scale of 48 miles to 1 inch.

Latitude. ° °	*a* in Ins.	*b* in Ins.	*d* in Ins.	*c* in Ins.	Latitude. ° °	*a* in Ins.	*b* in Ins.	*d* in Ins.	*c* in Ins.
From					From				
4 to 6	2·863	2·875	2·866	4·054	26 to 28	2·869	2·592	2·546	3·851
6 ,, 8	·863	·866	854	·047	28 ,, 30	·869	·546	·498	·820
8 ,, 10	·863	·854	·838	·037	30 ,, 32	·870	·498	·446	·788
10 ,, 12	·864	·838	·819	·025	32 ,, 34	·871	·446	·392	·754
12 ,, 14	·864	·819	·797	·011	34 ,, 36	·872	·392	·334	·719
14 ,, 16	·865	·797	·771	3·994	36 ,, 38	·873	·334	·274	·683
16 ,, 18	·865	·771	·742	·976	38 ,, 40	·874	·274	·211	·645
18 ,, 20	·866	·742	·709	·955	40 ,, 42	·875	·211	·145	·606
20 ,, 22	·866	·709	·673	·932	42 ,, 44	·876	·145	·076	·567
22 ,, 24	·867	·673	·634	·907	44 ,, 46	·877	·076	·005	·527
24 ,, 26	·868	·634	·592	·880					

CHAPTER XVII.

THE CONNECTION BETWEEN THE GREAT TRIGONOMETRICAL AND REVENUE SURVEYS—RATIO OF ERROR—EXTENT OF COUNTRY FOR SURVEY, AND AVERAGE COST PER SQUARE MILE.

No Revenue Survey can be considered complete and satisfactory unless the errors committed, and the degree of accuracy attained, are distinctly reported on. Without this is scrupulously observed, no confidence can be placed in its results, and as no work whatever, executed by human means, can be free from error, all that is reasonably expected is, that unavoidable errors should not exceed the lowest practicable limits. Every great National survey has a limit of error assigned, and all work exceeding this limit is rejected.

Ratio of Error.

In the large triangulation of the Great Trigonometrical Survey of India, where of course the greatest refinement and most scrupulous care is observed, an error of *one inch* per mile or $\frac{1}{63360}$ in part, amounts to 500 inches, or 42 feet, or nearly half a second of latitude in 500 miles, which is the distance between some of the bases. The work is reckoned liable to *half* this error when executed with the great theodolite, and equal to the degree of correctness indicated by an inch per mile, when performed by 18-inch instruments for the subordinate series of triangles; with inferior instruments, or a less careful system, the accumulation of error would be a *foot* per mile, which is equal to a ratio of $\frac{1}{5280}$ in linear dimensions, or $\frac{1}{2640}$ in area, or $\frac{1}{20}$ per cent. or 6 seconds in the above distance.

But men trained to this degree of exactness are out of their place in the detail measurements of the Revenue Survey; the valuable qualities of the Trigonometrical Surveyor, which he is obliged to maintain with such care, viz., delicacy of eye and touch, and rigorous modes of thinking, would be injurious in the details, and there would only be a loss of time in changing from one work to the other. They require in fact people differently trained, with instruments of different calibre, and of different constitutions of mind. The Trigonometrical, from being freed from details, has been able to progress more rapidly, and the great object has been to get the large triangulation out of hand—without it nothing systematic or really trustworthy can be done. Indeed the principal, and the detail

work, never could have gone on *pari passu*, and if the latter is based on the triangulation, it cannot be liable to any great accumulation of error, and may be taken up and organized according to the scale required.

The maximum error allowed, in lineal measurement on the Revenue Survey, according to the test it is submitted to by traverse proof, is 10 links in 100 chains, equal to 5·28 feet per mile; but in the actual prosecution of the extensive surveys of the season 1847-8, covering an area of about 16,000 (sixteen thousand) square miles, the average ratio of correction employed for the closing of the traverses, is found to be only 2 *feet* per mile, or rather more than one-third of the allowed correction; $\frac{1}{10}$ per cent. therefore for the pergunnah or main circuit measurement is fully within practicability, $\frac{1}{10}$ per cent. also may be allowed for the area of the district, $\frac{1}{2}$ per cent. for the village survey area, and 1 per cent. for the interior detail measurement of cultivation and waste.

These are exclusively the errors of measurement. As the computation of the Revenue Survey is based upon the wrong assumption of the earth's surface being *a plane*, certain discrepancies, no doubt, will arise from this circumstance; but these are invariably very small in comparison with the errors of measurement, as will be evident from the inspection of the following Table, wherein it will be perceived that a Pergunnah, of the average area of 100 square miles, will demand an additive correction of 2,969 *square feet*, on account of the sphericity of the earth, to give the absolute superficial surface or contents of the circuit; the required correction is, however, too small to make its omission of any consequence in a Revenue Survey operation:—

Computed plane Area of the Revenue Survey.	Correction for reducing the plane to the spherical Area.	Computed plane Area of the Revenue Survey.	Correction for reducing the plane to the spherical Area.	Computed plane Area of the Revenue Survey.	Correction for reducing the plane to the spherical Area.
Sq. Miles.	Sq. Feet.	Sq. Miles.	Sq. Feet.	Sq. Miles.	Sq. Feet.
1	+ 0	10	+ 30	100	+ 2969
2	1	20	119	200	11875
3	3	30	267	300	26719
4	5	40	475	400	47501
5	7	50	742	500	74221
6	11	60	1069	600	106878
7	15	70	1455	700	145472
8	19	80	1900	800	190005
9	24	90	2405	900	240475

Connection between the two Surveys.

But the most severe test to which a Revenue Survey can be subjected, is the comparison of its results with those of the direct distances of a Trigonometrical Survey, and

that this comparison may be performed as readily as possible, a due and proper connection between the two Surveys is essential, and scrupulously maintained. When this is the case, the principle, agreeably to which the map of the former operation may be corrected by the latter, may be stated as follows:

Suppose A, B and C to be three points laid down by both these operations, A', B' and C' being the trigonometrical positions, while A'', B'' and C'' are the Revenue Survey sites thereof. (See page 353.) Now take the Revenue Survey map and place A' upon A'', and then if the trigonometrical line $A'B'$ be laid off agreeably to its azimuth, B' may or may not fall upon B'', most probably it will not do so. Again, when C' is protracted in the same way as B'', it will most probably be non-coincident with C''. Here is therefore a triangular tract of country ABC which is represented by two dissimilar triangles $A'B'C'$ and $A''B''C''$ possessing only a common point A. Assuming the trigonometrical area $A'B'C'$ as errorless, that furnished by the Revenue Survey, namely $A''B''C''$, must not only be shifted from its original position, but enlarged or compressed, as the case may be, so as to produce a perfect coincidence with $A'B'C'$. When this operation is gone through, the Revenue Survey points, comprised within the triangles $A''B''C''$, will fall into such positions as would make them correspond with the trigonometrical sites $A'B'$ and C'.

When the first triangle has been corrected, take the trigonometrical position D' of a fourth point D, and compare it with its Revenue Survey site D'', it is most likely that D' and D'' will have different positions. Forming as may be convenient, ABD or ACD or BCD into a triangle, its Revenue Survey value may, by a process similar to that just described, be made to agree with its trigonometrical value. In like manner the remaining parts of the Revenue Survey map may be altered, so as to make them conform to the correct areas of the Trigonometrical Survey.

When the several parts of a Revenue Survery map are altered in the way above mentioned, the corrections applied are supposed to be small, or if large, they are supposed to be in the same direction and proportional to the areas to be altered. When either of these is the case, a most perfect map will be obtained. But if the corrections are irregular, that is, if they demand unequal enlargement of the different parts of the map, or an unequal compression of them, or if some corrections require enlargement and others compressions, the corrected map, in altering the relative positions of villages, would furnish a distorted

representation of the country, which would decidedly be inferior to the original uncorrected map, which perhaps did not contain these distortions.

The following comparative Tabular Statement of the numerical values of surveys conducted both in the North-Western Provinces as well as in Bengal, and performed at an interval of 17 years, will best illustrate the preceding remarks :—

Revenue Survey of 1832 *compared with the Trigonometrical Survey.*

Distances.	From Revenue Survey.	From Trigonometrical Survey.	Error.	Error upon 1 Mile.
	feet.	feet.	feet.	feet.
Saini to Saroli	96989	97017	— 28	1·63
Sani to Sirdana	67571	67639	68	5·16
Sani to Dholri	107906	108018	112	5·58
Saroli to Dholri	89681	90249	568	33·50
Saroli to Sirdana	31170	31194	24	4·07
Godhna to Saini	214296	214886	590	14·54
Babin to Chapra	116637	116046	591	26·66

These distances are deduced from the Tables of the Meridional and Perpendicular Co-ordinates on Page (352).

Revenue Survey of 1849 *compared with the Trigonometrical Survey.*

Distances.	From Revenue Survey.	From Trigonometrical Survey.	Error.	Error upon 1 Mile.
	feet.	feet.	feet.	feet.
Calcutta Base North End to Barrackpore Flag Staff ..	19850	19869	— 19	4·89
Ditto North End to Armenian Church, Chinsurah ..	66636	66721	85	6·72
Ditto North End to Fort William Flag Staff ..	55987	56051	64	6·03
Samalia to Sarisa	70222	70326	104	7·81
Sarisa to Diamond Harbour Semaphore	22092	22147	55	13·11
South End Base to Fort Flag	25364	25394	30	6·24
Fort Flag to Samalia	53921	53953	32	3·13
North End Base to Chinsurah	63505	63598	93	7·72
Chinsurah to Boga	64061	64167	106	8·75

These distances are deduced from the succeeding Tables of the Meridional and Perpendicular Co-ordinates.

Extract from the Delhi and Saharunpur Revenue Survey.

Stations.	Distances from the Jama Musjid of Delhi, Meridian.	Distances from the Jama Musjid of Delhi, Perpendicular.
Tower at Godhna	N. 5347	E. 3205
Church at Sirdana	„ 2733	„ 1849
Tower at Saini	„ 2142	„ 2685
Tower at Saroli, near Sirdana	„ 2831	„ 1387
Tower at Dholri	„ 1487	„ 1187
Tower at Karol	S. 2641	„ 1530
Tower at Babin	„ 3812	„ 181
Platform at Chapra	„ 5044	W. 1086

Extract from the 24-Pergunnahs Revenue Survey.

Stations.	Distances from the North End Calcutta Base.	
	Meridian.	Perpendicular.
Barrackpore Flag Staff	N. 283·19	W. 101·30
Armenian Church, Chinsurah	„ 1000·31	E. 136·93
Fort William Flag Staff	S. 823·99	W. 201·59
Samalia Tower	„ 1543·78	„ 587·87
Sirisa Tower	„ 2541·88	„ 955·26
Diamond Harbour Telegraph	„ 2876·66	„ 958·71
South End Base to Fort Flag	„ 310·06	„ 226·97
Fort Flag to Samalia	„ 719·79	„ 386·28
North End Base to Chinsurah	N. 952·71	E. 134·84
Chinsurah to Boga	„ 970·17	„ 30·93

The distances in these Tables are given in terms of Gunter's chain of 66 feet in length.

Suppose A and B are two points, the distance between which is required to be computed, calling m and p the meridional and perpendicular co-ordinates of the former point, and m' and p' the like co-ordinates of the latter; then the distance of A to B will be equivalent to $\left\{(m \backsim m')^2 + (p \backsim p')^2\right\}^{\frac{1}{2}}$ That is to say, the required distance is the hypothenuse of a right-angled triangle, whose sides are $m \backsim m'$ and $p \backsim p'$. As for example, the distance from

$$\text{Saini to Saroli} = \left\{(2831 - 2142)^2 + (2685 - 1387)^2\right\}^{\frac{1}{2}}$$
$$= 1469{\cdot}53 \text{ chains} = 969{\cdot}89 \text{ feet.}$$

It should be borne in mind, that when either the meridional or perpendicular co-ordinates happen to be of different denominations, the square of the *sum* of the co-ordinates so differing will require to be taken in lieu of the square of their *difference*. Thus the distance from

$$\text{Bahin to Chapra} = \left\{(5044 - 3812)^2 + (181 + 1086)^2\right\}^{\frac{1}{2}}$$
$$= 1767{\cdot}23 \text{ chains} = 1166{\cdot}37 \text{ feet.}$$

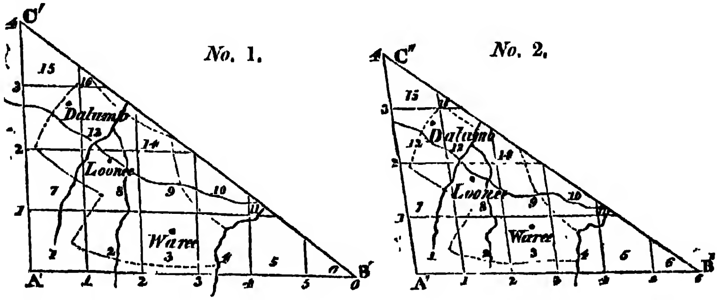
From an inspection of these Tables, it will be seen that the errors committed on the two Revenue Surveys range from 1·63 to 33·50 per mile on the former, and from 4·8 to 12 feet per mile on the latter, and they all lie in the same direction, the Revenue measurement being in defect of the Trigonometrical Survey. Taking the smaller of these discrepancies as the error of the Revenue Survey unit, it will be seen that the greatest error actually committed in the more recent operations is only 7 feet per mile.

The azimuth of any side of the large triangles likewise proves a check on the deduced azimuth of the Revenue Survey as conveyed from one main circuit to another, and this comparison is carefully carried out when opportunity is afforded for so doing.

Having explained in a general way the principle agreeably to which the details of a Revenue Survey may be combined with the results of a trigonometrical operation, we will now proceed to describe the mechani-

[PART III.

cal process whereby that combination may be effected in practice. For this purpose, retaining the characters already used, we will represent by $A'B'C'$ the Trigonometrical, and by $A''B''C''$ the corresponding Revenue Survey triangle. Of the three angles of the former triangle suppose A' to be nearest to a right angle, now take the sides $A'B'$ and $A'C'$ adjacent to this angle and divide the former into m and the latter into n equal parts, m and n being two independent numbers. This done, draw through the dividing points of $A'B'$ parallels to $A'C'$. In like manner, through the dividing points of the latter, draw lines



parallel to the former. This will divide the triangle $A'B'C'$ into a certain number of spaces, the greater part of which will be parallelograms, and the remainder, triangles, as shown in diagram No. 1.

After the trigonometrical triangle $A'B'C'$ has been divided in the way above described, the corresponding Revenue Survey triangle $A''B''C''$ may now be subjected to a similar operation by dividing the side $A''B''$ into m and $A''C''$ into n equal parts, and by drawing through the dividing points of either line parallels to the other. This is done in diagram No. 2, and the spaces into which the triangle $A''B''C'$ is divided, are analogous to those contained in the triangle $A'B'C'$, the corresponding spaces in the two figures being marked by the same numerals.

When this preliminary division of the Trigonometrical and Revenue Survey triangles has been made, the details from each of the revenue spaces are *sketched* into the corresponding trigonometrical space. When the sketching of all the spaces is completed, the Revenue Survey details will stand transferred into the Trigonometrical Survey map.

It ought to be observed at this place, that this operation of sketching, which is performed by the hand and the eye, is a guess procedure, and that supposing it to be executed as skilfully as possible, it will always be liable to some error. This error, however, will be reduced to minimum,

if the spaces to be sketched are sufficiently diminished in size. For this purpose the most convenient form for a space of this kind is that of a parallelogram, right-angled, or as nearly right-angled as possible, with sides varying from one-fourth to one-third of an inch in length. The first of these conditions will be attained by constructing the small parallelograms upon those two sides which contain either a right angle or an angle which is more nearly a right angle than either of the remaining angles of the given triangle. As to the second condition, it will always be in the power of a draftsman to fulfill it, by assigning proper values to m and n, taking care that these values come under any of the following forms, 2^p, 3^q, $2^p \times 3^q$, the exponents p and q being any integral numbers whatsoever. When the numerical values of m and n are taken equivalent to powers of 2 and 3, or to the products of those powers, the division of a given line into a required number of equal parts will become as easy as possible, it being carried on by continual bisection or trisection of distances, or by those two operations taken combinedly.

One advantage attending the combination of the Revenue with the Trigonometrical Survey, consists in the cancelment of the errors of measurement, which are almost unavoidable in the former operation. The second advantage of such an incorporation is the elimination of those small discrepancies in computation, proceeding from the wrong assumption made in the Revenue Survey of the earth being *a plane*. But there is a third, and perhaps the most important advantage, accompanying the union of the two surveys, which consists in the reference of the Revenue Survey details to proper meridians and parallels. From the manner in which a Revenue Survey is conducted, it may be easily inferred that those lines can never be drawn with any accuracy in the plan of that operation. On the other hand, they can be laid off with the greatest exactness in a trigonometrical map, from the known latitudes and longitudes of the trigonometrical stations contained in it. Suppose the operation of drawing the meridians and parallels is executed in a trigonometrical map, whereto the Revenue Survey details have been transferred, it is evident that that operation will fix the latitudes and longitudes of those details,—a determination which will obviously enhance their value as geographical materials, in putting them in an available state for the formation of the general atlas of the country.

It is desirable that the triangulation should always precede the Revenue Survey; it frequently happens, however, that in such a large country as India the triangulation has not extended over the district marked for the

Revenue operations. In this case it becomes necessary to fix very carefully all the conspicuous objects and triple-junction Pergunnah Stations from one *permanent point of departure.* From this first station, which should be a masonry pillar built expressly (if no convenient object presents itself), all the co-ordinate distances are computed, and are referrible at any subsequent time to the data produced by the Trigonometrical Survey, so that an union with it may afford the means of rectifying the topographical maps. The stations are likewise marked as durably as the means at the disposal of a Revenue Surveyor will permit, and properly connected with every available surrounding object of a permanent character, with a view of easy identification; with the aid of a proper map of the district, and full descriptions of all the stations so fixed, the Trigonometrical Surveyor has no difficulty in taking them all up as secondary points. If the first point of departure is fixed astronomically, it is considered only temporary, being replaced afterwards by values given by the Great Trigonometrical Survey, which are strictly correct as to relative positions, and with which no astronomical measurements executed by a Revenue Surveyor, can pretend to compete.

Progress of operations.

From the year 1822, when the Revenue Surveys first commenced, up to the year 1830, the rate of progress at which the operations proceeded was extremely limited. Only 3,020 square miles, a little more than half a square degree, had then been performed in seven years, with ten officers employed in the department, the annual rate of progress of each Surveyor ranging from 50 square miles to 338 as a maximum, and at this rate it was estimated that the area of Bengal and the North-Western Provinces, being about 310,000 square miles, or 77 square degrees, would require 481 years to accomplish.* The officers employed in those days, however, had little or no assistance, and the duties performed then by the Revenue Surveyor himself, are now entrusted to competent assistants and sub-assistants with large native establishments under them, whilst the Surveyor acts as a Superintendent over the whole as described in a former Chapter, the result of which has been, that during the last 23 years, or since 1830, the whole of the North-Western Province Districts, all Behar and Orissa, and a considerable portion of Bengal Proper, have been completed as detailed in the following page; no less than 46 districts of unsettled estates, amounting to 101,519 square miles, and 17 districts of Bengal

* Account of the present system of Survey, &c. By Captain Herbert, Deputy Surveyor-General. Calcutta, 1830.

and Behar perpetually settled estates, yielding an area of 62,226 square miles, have thus been surveyed in detail and mapped, leaving 16 districts, of Bengal, comprising 49,059 square miles, for survey, four districts of which are now in hand.*

In addition to this, the newly-acquired territory of the Punjab and Cis and Trans-Sutledge States have come under the Revenue operations, and afford a fine field of employment for the department.

Extent of Country for Survey.

The total area of the British possessions in India, including Sindh, Punjab, Jullundhur Doab, and Tenasserim, has been carefully estimated at 800,758 square miles, and the Native States at 508,442 square miles, making a grand total of 1,309,200 square miles, as the area of British India. This vast superficial extent of territory is confined within a length of 11,260 miles of external boundary. The *inland* frontier, from Tenasserim round by the Himalayan range of mountains, to Cape Monze in Sindh, is 4,680 miles, whilst the *coast* line, from Singapore round the Bay of Bengal, up the Malabar Coast to Kurrachee, is 6,580 miles; total circumference 11,260 linear miles. Of the Native States about 200,000 square miles are already surveyed, leaving about 308,442 almost all wild

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* UNSETTLED DISTRICTS SURVEYED.

1. Panceput.
2. Hurrianah.
3. Delhi.
4. Rohtuck.
5. Goorgaon.
6. Suharanpore.
7. Mozuffurnuggur.
8. Meerut.
9. Boolundshuhur.
10. Allyghur.
11. Bijnour.
12. Moradabad.
13. Budaon.
14. Bareilly.
15. Phillibeet.
16. Shahjehanpore.
17. Muttra.
18. Agra.
19. Furruckabad.
20. Mynpooree.
21. Etawah.
22. Cawnpore.
23. Futtehpore.
24. Humeerpore.
25. Banda.
26. Allahabad.
27. Goruckpore.
28. Azimghur.
29. Jounpore.
30. Mirzapore.
31. Benares.
32. Ghazeepore.
33. Jaloun.
34. Dehra Doon.
35. Bhuttianah
36. Sohagpoor.
37. Ramghur.
38. Ajmeer.
39. Mairwharra.

† Total, N. W. P.

40. Pooree.
41. Cuttack.
42. Balasore.
43. Cachar.
44. Jynteah.
45. Chittagong.
46. Assam.

SETTLED DISTRICTS SURVEYED.

47. Midnapore.
48. Hidgelee.
49. Hooghly.
50. Shahabad.
51. Sarun.
52. Patna.
53. Monghyr.
54. Behar.
55. Purneah.
56. Tirhoot.
57. Maldah
58. Bhaugulpore.
59. 24-Pergunnahs.
60. Rajshahye.
61. Beerbhoom.
62. Baraset.
63. Goalparra.

63. Total surveyed.

DISTRICTS UNDER SURVEY.

1. Nuddea.
2. Moorshedabad.
3. Pubna.
4. Mymensing.

4. Total.

DISTRICTS REMAINING FOR SURVEY.

1. Jessore.
2. Burdwan.
3. Bancoorah.
4. Dinagepore.
5. Bograh.
6. Rungpore.
7. Dacca.
8. Dacca Jellalpore.
9. Backergunge.
10. Sylhet.
11. Tipperah.
12. Bullooah.

12. Total.

The above statement is only up to date of second edition.

† The whole of the Districts of the N. W. Provinces are under resurvey in 1874. See also note, page 360. The first survey of the whole of the British revenue-paying Districts may now be said to have been completed.

hilly jungle and of little value, to be taken up.* The proper mode of filling up these extensive tracts of country, which are not likely to come under the operations of the *Revenue* Survey (supposing the latter to be confined to our own or the Regulation Provinces), will be by minor Triangulation and the Plane Table. The 1 inch or 1 mile = 1 inch scale will perhaps be the most suitable for the nature of most of these countries, of which, on account of their connection with us, the liability to lapse to the paramount power, and likelihood of becoming the scenes of military movements, we require to have a good general survey. For topographical work, in filling in triangulation with the Plane Table, one man ought to be able to survey 16 square miles per diem, viz., 4 miles by 4 miles—on the ¼ inch or 4 miles to 1 inch scale, or per season of six months' duration, about 2,500 square miles. For the ½ inch or 2 miles = 1 inch scale, only 4 square miles per diem can be executed, or about 600 square miles per season, and so on inversely as the squares of the scales.

Of the area above-mentioned the countries lately lapsed to the British, and which may now be seen within the red color on the published maps, have been included. The Jullundhur Doab, with the Kohistan, is about 16,400 square miles, and the Protected Seikh and Hill States, 15,187 square miles; the Punjab Proper may be said to be 78,000 square miles more, and these provinces are now gradually coming under the *Revenue* operations. Indeed, 20,000 square miles of the Cis and Trans-Sutledge States have actually been completed.† The province of the king of Oudh may likewise lapse some of these days—its area is 23,738 square miles. The Gwalior territory comprises 33,119 square miles, and the Saugor and Nerbudda, 33,775 square miles.

Of the Native States some of the following are the most conspicuous :—

Estimated Area.	*Sq. Miles.*	*Estimated Area.*	*Sq. Miles.*
Oudh (Lucknow) (*a*)	23,738	Bhopal	6,764
Mysore	30,886	Rewah	9,827
Hydrabad (Nizam's)...	95,337	Protected Seikh and Hill States ...	15,188
Jodhpoor	35,672	Oodeypore	11,614
Gwalior (Sindhia)	33,119	Sattara	9,061
Bhawulpoor	20,003	Kolapore	3,445
Jummoo Territory (Kashmir) ...	25,123	Cutch	6,764
Berar (Nagpore) (*a*)	76,432	Kotah	4,339
Jeypore, &c. (Rajputana)	15,251	Indore	4,467
Bickaneer	17,676	Travancore	4,722
Jeysulmeer	12,252	Ulwur	3,573
Baroda and Kattywar	24,249	Bhurtpore	1,978
Jhansee (*a*)	15,5700		

(*a*) Now lapsed to the British.

† In addition to the whole of the Cis and Trans-Sutlej States, the following districts of the Punjab Proper have now been completed; viz., Goordaspoor, Umritsur, Lahore, Sialkote, Goojrat, and Goojranwallah, embracing an area of 13,458 squaremiles. July 1854.

Average Cost.

As a sample of the progress now made by the combined efforts of the officers employed on this side of India, and the cost at which the work is performed, the following analysis of the general average rates per square mile, with the total area completed, is given for the North-Western Provinces from the year 1833, and for Bengal from the year 1838, the first commencement of operations, down to the present time. The average for the North-Western Provinces in the 15 seasons' work amounts to Rs. 22-5-8 per square mile, and for Bengal it is in a similar period Rs. 26-12-1 per square mile, whilst the general average on the whole area executed is only Rs. 20-3-8 per square mile. In the two seasons of 1847-48 and 1848-49, upwards of 16,000 square miles of country appear to have been sur-

North-Western, Upper, and Central Provinces.				*Bengal or Lower Provinces.*			
Season of Survey.	Area Completed.	General Average Rate per Square Mile.		Season of Survey.	Area Completed.	General Average Rate per Square Mile.	
	Sq. Miles.	Rs.	As.		Sq. Miles.	Rs.	As.
1833–34	3747	29	4	1838–39	1901	60	0
34–35	5282	24	7	39–40	2450	49	9
35–36	5391	27	5	40–41	5145	23	3
36–37	7455	23	15	41–42	9132	22	5
37–38	12400	13	7	42–43	6035	20	13
38–39	10974	13	15	43–44	7079	18	4
39–40	12698	11	12	44–45	7043	16	10
40–41	12698	11	12	45–46	8967	12	10
46–47	3583	20	1	46–47	7429	14	9
47–48	8997	14	4	47–48	7097	18	2
48–49	9188	13	3	48–49	6213	21	0
49–50	6792	19	7	49–50	4874	25	11
50–51	2481	43	1	50–51	3565	36	0
51–52	3301	36	12	51–52	3826	31	5
52–53	4216	32	7	52–53	4246	31	0
Total..15	109203	22	5	Total..15	85032	26	12

	Area in Sq. Miles.	*Cost in Rs.*	*Rate.* R. P. A.
Total of the two Provinces..	194235	39,28,866	20 3 8

Since the above date, the whole of Oudh, Jhansee, Bhurtpoor and Bhawulpoor have been taken up on the Revenue system, whilst Dholpoor, Gwalior, Bhagelkhund (Rewah), Bundelkund, Tonk, Jeypoor, Kotah, Ulwur and other parts of Rajputana have been surveyed on the inch scale; Bhopal and other parts of the Central India, and Rajputana Agencies are now under survey, and a very large area, extending from the Chumbul to the Nerbudda Rivers, has been effected; Kashmir, Jamoo, the protected Seikh and Hill States have all been laid down on the *half-inch* scale. Kattywar, Guzrat and other Bombay Native States between the Nerbudda and the Taptee Rivers, are in progress, as well as Kumaon and Gurhwal on the inch scale.

In the last printed Annual Report of the Surveyor-General for 1873, the following figures represent the aggregate results of the more modern Topographical and Revenue Surveys, brought up from the year 1847 to the present date:

Area accomplished, 743,802, sq. miles. Total Cost, Rs. 2,00,28,330.

This best shews the past history of the Survey Department and what has been effected of late years.

[PART III.

veyed by the united exertions of eight different parties in the two provinces.*

It appears that as the surveys advance, the cost per mile in each succeeding year tends to reduction, caused by the facility acquired by the well-trained establishments and the very efficient mode of working them exercised by the Superintending Officers. The expense of a Revenue Survey, however, is much influenced by local peculiarities, and, even allowing for the difference amongst Surveyors, some being more skilful, active, and capable than others under precisely the same circumstances of doing more work, it often happens that the utmost endeavours of the most energetic officers will not produce so low a mileage cost, as others who have more favoured ground to go over. In the circuit system work of the Revenue Surveys, *the size of the villages* is the grand secret; if the average size is large, above a square mile, as in the North-Western Pro-

* The progress and general cost of the *Revenue* Surveys brought up to the commencement of the year 1874 is as follows:—

North-West, Upper, and Central Provinces.					*Bengal or Lower Provinces.*				
Season of Survey.	Area Completed.	Total Cost.	General Average Rate per Square Mile.		Season of Survey.	Area Completed.	Total Cost.	General Average Rate per Square Mile.	
	Sq. miles.	Rs.	Rs.	As.		Sq. miles.	Rs.	Rs.	As.
1853–54	9150	2,13,568	23	5	1853–54	5490	1,43,094	26	
54–55	14822.5	2,81,808	19	0	54–55	4038	1,43,730	35	
55–56	12111	2,63,888	21	12	55–56	6203	1 62,576	26	
56–57	17619	3,09,710	17	9	56–57	6966	1,76,183	25	4
57–58	10932	2,42,301	22	2	57–58	5765	1,68,046	28	4
58–59	13274	2,41,402	18		58–59	6132	1,95,518	31	14
59–60	11964	2,48,433	20	12	59–60	8263	2,27,934	27	9
60–61	16881	2,89,539	17	2	60–61	8645	2,21,191	25	9
61–62	11253	3,05,001	27	1	61–62	10643	2,46,554	23	2
62–63	14208	3,50,621	24	10	62–63	9728	2,60,733	26	12
63–64	20369	4,53,111	22	3	63–64	9915	3,54,763	35	12
64–65	14415	4,53,369	31	7	64–65	7857	3,51,744	44	12
65–66	9652	4,40,143	45	9	65–66	6110	3,47,157	56	13
66–67	8476	4,60,744	54	5	66–67	4523	3,87,852	85	[illegible]
67–68	10297	5,27,677	51	3	67–68	6319	3,57,251	56	8
68–69	13973	5,29,239	37	14	68–69	4953	3,09,093	62	6
69–70	14494	5,11,026	35	4	69–70	6445	3,02,113	46	14
70–71	10596	5,09,102	48	0	70–71	6342	2,55,643	40	5
North-West Provinces and Punjab.					*Bengal, Bombay, and Central Provinces.*				
1871-72	†7160	2,44,161	34	1	1871-72	10087	4,64,596	46	0
72-73	†7833	2,24,711	28	11	72-73	6809	4,25,659	62	10

† Exclusive of Cadastral Surveys, *viz.*:—

	Area in Square Miles.	Cost, Rs.
1871-72	897	1,83,385.
72-73	1870	3,47,514.

vinces, a good outturn may be expected, and consequently a reduced cost; but in Bengal, where the villages do not average above *half* a square mile, it is impossible to compete with the extraordinary cheapness which some of the old Surveyors attained, neither indeed is such a thing desirable with reference to the accuracy demanded in the present day. If 3,000 square miles and upwards is given in by a single Surveyor, the results must partake of that haste with which the country is got over, and eventually prove of an inferior order.*

A survey establishment is always proportionally more expensive, the less complete it is; the chief expense being the salary of the Superintendent and the European Assistants. It should therefore be kept up in as effective a state as possible, with a view of turning it to the best account, and by a proper division of labor, as economical a survey may be obtained as local circumstances will permit. At the average rate of progress already made in the Bengal provinces, it may fairly be anticipated, that what remains to be done will not occupy a longer period than ten years more, when, in addition to a good Topographical Survey, we shall have a complete and detail record of every estate paying revenue to Government, and at the present average rates the cost may be calculated at about 11½ lacs of rupees, which, added to 15½ lacs already expended, will make 27 lacs as the entire expense for Bengal, Behar, and Orissa.†

* The rise in the average rate during the past few years may be accounted for by the change in the nature of the country under survey, as well as from the intricate detail of the work, and the minuteness with which it is now laid down. July 1854.

† Since the last edition of this work, now nearly 20 years ago, great progress has been effected in the survey of India, not only by the revenue operations on the larger scale in the regular districts paying revenue to Government, but also by the Topographical Branch of the Department organised of late years and constituted expressly for dealing with the Native States, comprising for the most part hilly, rugged, and difficult jungle-clad country, on the 1-inch scale. Great changes have also been made in the mode of carrying on the different surveys, and in the constitution of the Department as regards organization and expense, which have materially effected the average mileage rates of the operations.

With reference to what has been shown in the above Chapter, the whole of the districts of the Punjab, the Central Provinces, Sindh and Lower Bengal, Assam, &c., have now been completed. The N. W. Provinces have recently been recommenced, the old survey of 1825 to 1835 being obsolete and unconnected, and the records for the most part lost in the mutiny. Revised surveys of a few districts in the Dehli and Hissar Division, as well as in the Derahjat of the Punjab, on larger scales, are in progress, together with certain districts in the Bombay Presidency, with the object of supplementing the Revenue Assessment Survey there, sufficiently to produce good Topographical maps hitherto not attainable.

CHAPTER XVIII.

On the Khusrah or Native Detail Measurement of "Fields."

Preliminary Remarks.

The chief object of the Revenue Survey in India is either the formation of a new settlement with the zemindars and other petty landowners and tenants, or, where the provinces are perpetually settled under Lord Cornwallis' Act of 1790, as in Bengal and Behar, the defiuement of every estate on the Collector's Rent Roll, and to determine the relation of land to *jumma*, or revenue, by the ascertainment of the areas and boundaries of estates or mehals.

In very many instances, these estates are so small or so scattered and intermixed, that the professional or scientific survey is unable, on account of the enormous expenditure it would involve, to define such minute parcels of land. For the general purposes also of the current revenue business of the district, a record in the vernacular language is essential, and without which the people would be kept in ignorance of the result of the investigations pursued.

For this purpose, therefore, it is necessary for the Surveyor, in addition to his own scientific operations, to carry on a *khusrah* or *statement of measurement of land*, according to the native system, known and appreciated by the inhabitants of the district, and performed by natives, who are well acquainted with the nature of the tenures, the general capabilities of the soil, and the current dialect language.

Such a measurement of the North-Western Provinces has been entirely completed, and a settlement of the land tax concluded; but in the Lower Provinces, the records in the Revenue Collectors' Offices, and upon which the whole fiscal and judicial business is conducted, actually shew nothing more than the mere name of the estate and the amount of land tax (jumma) paid by the proprietor, and even this is frequently obscure and undefined, whilst the villages and portions of villages of which it consists, scattered perhaps in different parts of a pergunnah, are known only to the proprietor, or his agent. The chances, therefore, of an auction-purchaser obtaining uncontested possession of an estate are very remote, and in many cases where Government have become purchasers, the authorities have been unable to trace the lands composing the estate; or else, what

they have been successful in finding, has been insufficient to meet the jumma assessed. The absence of all authentic data regarding their districts, having long been severely felt by the local civil authorities, the Revenue Survey has been ordered to extend its operations over the whole of the Regulation districts of Bengal, and we propose to treat of the method of conducting an efficient khusrah measurement, and to explain the difference necessary to be observed in *Unsettled* Districts where the assessment follows in the train of the survey, and in the Perpetually *Settled* Provinces, where no settlement is intended, but for which a faithful record of estates paying revenue to Government is so much needed.

It must first be understood that the "khusrah" is a distinct operation altogether from the professional survey; the latter is performed on scientific principles, with first-rate instruments and by experienced Europeans and East Indians, aided also by natives trained and educated for the purpose; the former, on the contrary, appears to be conducted by the rudest methods, and by an inferior, though intelligent class of natives, the only instrument used being a rope, rod or chain, according to the primeval custom of the district, with no compass, or anything but his eye to guide him, the native Ameen is expected to measure a village, the total area, which must agree with the area defined by the professional survey within a certain percentage, and to deduce the intermediate detail areas of every species of "*land under cultivation*," "*thrown out of cultivation*," that which is "*fit for cultivation*," "*waste or jungle*," *sites of villages and gardens*," "*topes of trees*," &c., the separate contents of which shall, in the aggregate, make up the correct total area of the village, to form the basis of the Revenue Assessment of the *mouza* or village.

As a general rule, the term "*measurement*" is always applied to the khusrah proceedings, while that of "*survey*" more properly belongs to the scientific or professional portion of the operations.

Demarcation of Boundaries.

As a preliminary and most important part of survey operations, the accurate demarcation of boundaries, and settlement of disputes, is carried on by a distinct establishment specially appointed for the purpose, and although this duty is not actually in the province of the Surveyor, forming as it does a judicial proceeding, still the working of the system, and its connection with the survey, should be fully understood, its notice here, therefore, will not be out of place. A Covenanted Civil Officer, vested with the powers of a full Collector, having a very efficient estab-

Plate XIII

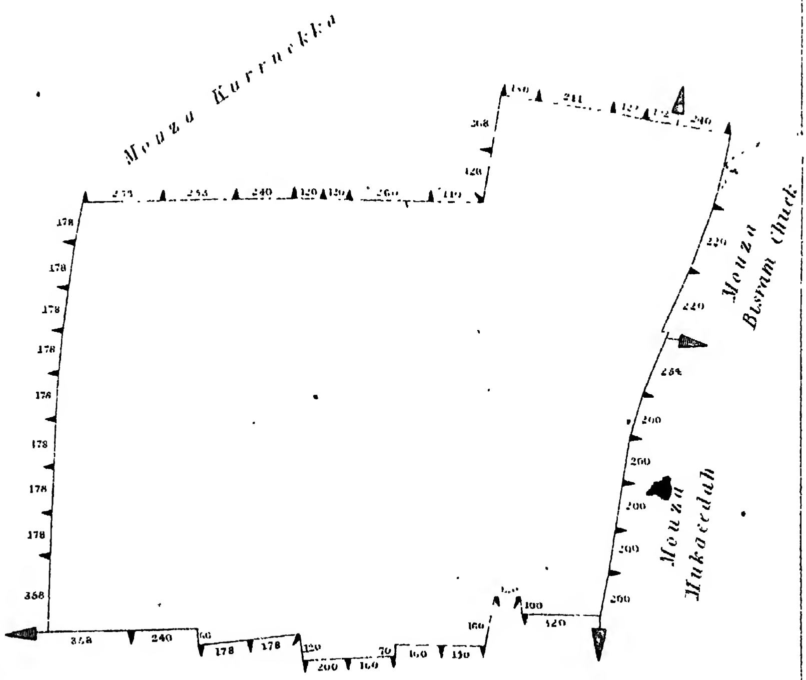
NORTH

Specimen of Thakbust Map

Mouzah Moosey'huree

Pergunnah Manjhee

District Sarun.



Mouza Burrahpoor

The distances are given in feet

Syed Naserallee and Dyal Chund Ameens

SOUTH

(Signed.) C Chapman Civil Supt. of Survey.

J. H. Lowry fc.

Published by W. Thacker & Co. London Calcutta & Bombay.

lishment under him, consisting of Uncovenanted Deputy Collectors, Peshkars, and Ameens, of the strength noted in the margin, precedes the survey in such a way, that the Surveyor may always find *adjusted* boundaries, and plenty of them, to keep his parties in full work. The chief object of this Officer is to keep so well in advance, that no hindrance whatever may occur to the Surveyor;

FOR 12 MONTHS.	
2 Uncovenanted Deputy Collectors, at 400	Rs. 9,600
4 Peshkars, at 40	" 1,920
12 Peadahs, at 3	" 432
FOR 6 MONTHS.	
40 Ameens, at 17 Rs. each	" 4,080
12 Peadahs, at 3	" 216
Per annum,	Rs. 16,248

he has to furnish a sketch map of the boundary of every village demarcated, exhibiting the points at which mud pillars (or *thâks*), or other marks, have been erected at certain measured distances, generally about 200 to 300 feet apart, together with a file, or *misl*, explaining the position of these marks and the names of adjoining villages. At every principal angle or bend of the boundary, a mud pillar (or *dhue*), such as is seen in the Frontispiece, is erected, and at all triple-junction points these distinguishing marks are found, about 5 feet high, and at the intervening distances smaller marks, bamboos, sticks, or smaller mud pillars suffice. An acknowledgment (*suppoordnameh*) from the several parties concerned as to the accuracy of the boundary laid down, and for the preservation of the marks pending the survey—and a memorandum by the ameen (*roodad*) explaining any peculiarities in the village—the nature and names of the included mehals or estates, and whether there are any other lands belonging to the village, detached in other parts of the pergunnah; or if it contains interlaced lands belonging to other villages—together with remarks as to the prospering condition of the village, or otherwise, the estimated proportion of cultivation to waste, and so on, are included in the file.

As soon as the Pergunnah is completed, a correct list of villages is made out, together with a general rough sketch, or congregated (*moojmillee*) map, exhibiting every village circuit in its proper relative position. These documents are forwarded for the use and guidance of the Surveyor, and without which it would be difficult for him to proceed. So much importance is placed on the due performance of this duty, that Surveyors are positively interdicted from surveying any boundary, unless they are in actual possession of the demarcation papers.

They are thus entirely dependent on the proceedings of the Settlement Officer for a fair field to labor in. When the marks are erected in the field they are frequently destroyed, both by the elements and by the village people; without, therefore, the sketch map to guide him, the

assistant employed on the boundary survey is liable to take up a wrong boundary. In some instances great confusion has arisen, and revision become necessary, from the absence or inaccuracy of these documents, the village demarcation (*Thakbust*) map, therefore, is required for constant reference, and is placed in the hands of the European Assistant, who undertakes the professional survey. A specimen of this map is given in Plate XIII, and it may be observed that the outline boundary should be sufficiently approximate to the map by actual survey, as to admit of easy comparison, and the professional map of every village must actually assimilate with this Thakbust before it can be passed, a statement to this effect being appended to every map by the Surveyor. In some districts, however, the maps are not so good, the bends and turns in the boundary being sketched in, without reference to their actual length by measurement, and which frequently distorts the shape of the circuit very considerably, rendering a comparison with the true surveyed boundary impracticable. To obviate this a scale has been introduced and even a compass put into the Thakbust Ameen's hands, with which he goes round the circuit, taking a bearing for every bend, and laying the same down on his map by the aid of a paper protractor. This system is now generally introduced in Lower Bengal, where the intricacies of the boundaries, and the insubordinate conduct of both landowners and ameens rendered it more than advisable to adopt some further check on the demarcation operations, to prevent, if possible, the system of guess work, so frequently resorted to by the latter class of persons.

The nature of the village boundaries in Bengal is such that it is feared even the present complete and expensive operations are insufficient to enable entire confidence to be placed in the maps; without any *natural* boundaries or permanent landmarks, there is no method by which the lines and bends represented on the maps, and called boundaries, can be proved mathematically; and until a more stringent law is enacted, to make the investigations now carried on permanent and unalterable, even in the Civil Courts, the zemindars will oppose and obstruct, and be perfectly indifferent to the recorded boundary of their villages, knowing that the question of their *rights* of property is not affected by the investigations under Regulation VII of 1822, by Uncovenanted Deputy Collectors, or even by the Settlement Officer who exercises the powers of a Collector.

It is very evident that with such precautions, and with such labor and expense, if village boundaries, obtained by three distinct investigations, compared and found critically to coincide one with the other, and all disputes carefully settled and decided, as well as attested by surrounding

zemindars, are afterwards to be impugned, and on subsequent complaint in the Civil Courts, are found to be at variance with the absolute limits of the estate as then pointed out, then no blame can be attached to any one but the zemindars themselves, combining together fraudulently to mislead, or else carelessly indifferent or ignorant of that which the Government takes such pains to ascertain. By making the proprietors of the soil fully alive to the final importance of the survey operations as regards their *rights*, this evil can alone be remedied. The result of the survey in Bengal may then prove of equal value to the Government as it now does in the North-Western Provinces. In every local Court the survey records are there appealed and referred to, with confidence, to the unbounded advantage of every department of public business, and the ease and relief of every official.*

The present extent of survey establishments, and the rapid and efficient manner in which they have been brought to carry on their operations, renders it imperative on the Settlement Officer to be at least one season in advance with the demarcations. Without this, the Surveyor could not take the field in December with any chance of finding uninterrupted work, and unless the demarcations are well *in advance*, the operations become a mere clog on the Surveyor, adding greatly to the expense of the survey, and rendering nugatory also the heavy expense of the revenue investigations. It will also be apparent that the utmost necessity exists for all the *disputed cases* to be properly adjusted and settled *prior to survey ;* without this *sine quâ non* double measurements must be resorted to, and the records of the survey not only delayed but thrown into confusion.

The Pergunnahs demarcated one season may occasionally require to have their *Thaks* or marks, which have been washed or blown away during the intervening rainy season, re-erected : for this purpose, merely a few Ameens sent round again early in October or November, are sufficient to induce the village authorities to replace the marks according to the investigations previously conducted, and thus Surveyors are amply provided for starting their work at the commencement of each field season.

* If a survey is not *permanently* marked by stone or masonry pillars, it must of necessity lose more than half its value as a record of rights, and in time become absolutely useless for the purpose of identification. This great principle is the more to be insisted on in an open plain country like Bengal and Behar, where natural landmarks are so very few. Unfortunately this important point has not yet been sufficiently realized as it deserves to be, by the Revenue Authorities of the Lower Provinces of Bengal.

Difference between Settled and Unsettled Provinces.

The "Khusrah," as well as the professional survey, is done *mouzawar*, or village by village. In *unsettled* districts it is necessary to measure by Khusrah every village, and carefully to investigate into all the details of the qualities of the soil, nature of the crops, and every other description of information tending to facilitate the assessment with every individual proprietor, and at the same time to preserve the rights of their subordinate *ryots*, or cultivators of the soil, by recording their separate *fields*, and the terms on which they hold them from the zemindar, and to render the duties of the Collector of Revenue or Settlement Officer, as plain and distinct as possible.

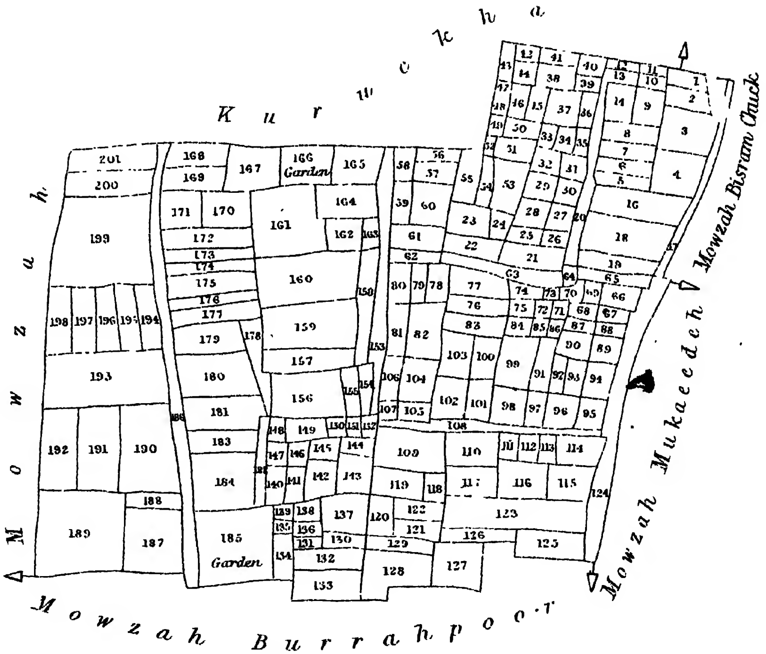
In *settled* districts the areas and boundaries of mehals or estates being all that is required, the professional survey is able of itself to ascertain this, when an estate consists of one or more integral and compact villages—and no Khusrah is therefore necessary. But where the villages contain such an intermixture of property that the professional survey is unable to define it, then the native measurement of *Fields* or *Khusrah* is essential to supply the deficiency. By these means the scattered lands of every mehal or village, however intricate, are brought together, and the aggregate areas thus obtained are recorded on the plans of the professional survey. The Khusrah measurement, therefore, is only resorted to when the division and intermixture of property is so minute and intricate that the details cannot be professionally surveyed except at a most disproportionate and unwarrantable expense. Where there may be only one or two parcels of intermixed lands in a village, of course the whole village should not be measured by Khusrah on that account, these parcels may easily be shown by the professional survey; but where estates are held *ijmallee*, or in shares, and the lands are divided field by field, *Khetbut* (in Behar phraseology), or *Petulgolah* (as it is termed in Bengal), the Khusrah, properly attested by the parties, is the only satisfactory, if not the only attainable, record of the state of the property. In *settled* provinces, therefore, only a small moiety of the villages come under the Khusrah operations, generally not more than about 15 per cent. on the entire area, and as the nature of the soil and crops is a point of secondary importance, the labors and anxieties of the Surveyor are greatly diminished, and a vast saving of expense also effected.

Specimen of Khusrah Field Map,

or Shujreh

Mowzah Mosehreemookhrah

Purg^h. Manjhee Zillah Sarun.



Shaghunlall Aumeen

(S^d) W^m Maxwell Lieut^t

Revenue Surveyor

Published by W. Thacker & Co.

CHAPTER XIX.

The Mode of Prosecuting the Khusrah.

The number of villages requiring this process being ascertained from the lists furnished by the Demarcation Officers, the Deputy Superintendent of Survey, at the commencement of the season, appoints as many Ameens as he calculates will be able to keep pace with the professional work (a very important point), and in most of the surveys of late years from 100 to 200 qualified men have been employed annually. The correct boundary of the village having been demarcated as before explained, the Ameen is deputed with suitable Perwannahs (written orders or summonses), and copies of the Thakbust papers, for his guidance; he proceeds at once to acquaint himself with the names of the chief proprietors, farmers and gomastas (or agents), and speedily enters into arrangements with them for commencing the measurement of their fields, and demands the records of any former measurement which may be in existence, to assist him in his investigations, and to enable him to have some clue as to the rights of property in the village. All preliminaries being settled, which takes a considerable time to effect with recusant and unwilling landowners on the one side, and exacting Ameens on the other, the Ameen commences to measure each field or plot of ground with the linear measure in general use in the Pergunnah or District, most commonly a rope of raw hemp, or a short bamboo held in the centre, and thrown down touching the ground at either end. Of late years iron chains have been more employed of a length to suit the local beegah. Every field is thus measured in the form of a parallelogram, by simply taking the length and breadth (or the mean of several measurements where the sides are unequal), the position with reference to the adjoining fields being also carefully recorded. The measurements, whatever they may be, are called out loudly, for the information of attending witnesses, and of the *rojo-nuvees*, or village writer, who follows the Ameen, and takes a verbatim copy for the satisfaction of the proprietors, and as a check against the Government functionary.

CHAPTER XIX.]

FORM OF THE KHUSRAH OR *CHITTAH.*

Mouza Ramchunderpore : Pergunnah Mydunmull : District 24-Pergunnahs.

This village is measured with a chain of 80 haths long, by Madhub Chunder Ghose, Ameen, in the Year 1848.

Number of Dagh, or Field.	Number on Towjee, or Collector's Rent Roll.	Name of Mehal.	Name of Malikan, or proprietor.	Name of Jotedar, and relative position of Fields with preceding one.	Length in Russees.	Breadth in Russees.	Area in Beegahs.	Description of Soil.	Crops.	REMARKS.
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
							B. C. C.			
1	255	Khoord Rajpore.	Horoloo11 Mittree.	Horee Patalee commenced on southern boundary of Gopal pore, on waste land of Kundanga.	2 16½	0 10½	1 14 10	Salee Putteet	....	Government holds a 4 ans. 12 gundahs share in this village.
2	260	Ditto.	Soonduree Dassee.	On South of above wasteland, Jotedar, Kistaroy Takoor.	1 7	0 17½	1 3 10	Ayum, or 1st quality.	Garden, &c.	The beegah is one russee of 80 pucka haths long, by the same breadth.

The Khusrah Field-book.

The field measurements are entered in a tabular form of the description shown in the preceding page, every holding and parcel of land differing in quality, or coming under the various denominations of settlements, whether (*lakheraj*) rent-free, &c., are recorded separately, each field being distinctly noted as lying to the north, east, south, or west of the preceding one, and distinguished by the name of the (*jotedar*) cultivator as well as proprietor, together with such other natural landmarks as may exist.

At the same time, with the entry of these particulars, the measuring Ameen constructs a *rough eye-sketch* (or *shujreh*) of the relative positions of all the fields, numbered to correspond with the Register or Field-book (*chittah*), and which therefore forms a complete index to this document. This map is merely traced by the hand, without scale, rule or compass—but by constant practice and a naturally quick eye, the Ameen is able to put each day's work together, so that when the whole village is completed, the exterior outline or contour of the boundary bears a sufficient resemblance to the professional map, as to admit of easy comparison, and considering the means employed, and the large number of fields so put together, averaging from 1,000 to 1,500—it is only to be wondered at, that such accurate and useful results are arrived at. Plate XIV is a specimen of an actual measurement prepared in the way described in the Sarun District. This map and register affords information to the most minute details, as to the position, size, and condition of fields, the roads, watercourses, nullahs, &c., within the limits of the village, forming a complete foundation for the abstract of estates (or *khatteeawoonee*) required for the purposes of assessment, or the Mehalwar Register, where no fresh settlement is needed. It must here be remarked that the *fields*, recognised and adopted on this side of India, are not arbitrary squares and parallelograms formed and moulded at the time of measurement, for the express convenience of the surveyors or revenue operations, but *bonâ fide* the small and intricate plots of land pointed out by the people of the soil according to their own divisions and subdivisions, and consistent with immemorial right and usage. They manage these things differently at Bombay, as will be seen from a published pamphlet quoted below.* Although there are some points connected with their mode of conducting the Khusrah, especially as regards the permanent fixture of the

* *Vide* Official Correspondence on the System of Revenue Survey and Assessment in the *Bombay* Presidency. Printed by order of the Government of Bombay, 1850.

boundaries, and the completeness and sufficiency of their law, and consequent understanding with the people, which might be followed with advantage, we extract three rules which would appear somewhat at variance with the preconceived notions on this side of India.*

The system of the Revenue Settlement Survey at Bombay appears very different to what we have endeavoured to describe in these pages, and it is not combined with a Professional Survey for the purposes of check, or the attainment of geographical information. Our space will not permit of entering further into a comparison of the mode of procedure between the two Presidencies, and we must refer the reader to the work itself for further information on the subject, as well as to the "Directions for Settlement Officers in the North-Western Provinces, published in September 1844," in which very full and valuable details are given as to the whole process of both Khusrah and Thakbust.†

In the definement of so many fields within a small area of perhaps 400 to 500 acres with a common rope, considerable error must be caused; in Khusrah measurements, however, it is not the mere error of bad tools and bad workmanship that is to be guarded against, but the most venal and nefarious practices, for which Ameens are notorious in all parts of India; the frauds and peculations they enter into with the Zemindars require the utmost energy, activity, and watchfulness of Superintending Officers to keep in check. The profession of a Surveyor is always onerous, but when he is invested with the charge of the Khusrah, in addition to his scientific operations, his duties become very arduous and full of anxiety, for without the most incessant check and control over his Ameens, scattered through perhaps 150 villages and a superficial area of one hundred

* Rule 1, page 4. "The number of acres for each description of soil and culture capable of cultivation by a single pair of bullocks having been determined, the size of the fields should be so regulated as to contain from this to *double this number* of acres."

Rule 7, page 21. "When two ryots hold a field, and one of them relinquishes his share, or dies without heirs, the share thus lapsing is to be offered in the first instance to the other sharer before it is offered to any other party, and in event of the said sharer declining it, and, no other party applying to take it up, *the former must relinquish his share too*, and allow the whole field to become waste!"

Rule 8, page 21. "When there are more sharers than two in a field, and any of them relinquishes a share, or dies without heirs, it should be offered as above to the sharers in the first instance, beginning, in event of their failing to settle the matter amongst themselves, with the largest sharer, and so on to the least. If none of these nor any other party be found to take up the relinquished share, *the whole field must be thrown up!*"

† See also "Translation of a proceeding (or complete Misl or File), regarding the settlement of a village according to the system pursued in the North-Western Provinces." Published under the authority of the Lieutenant-Governor in 1847.

square miles, he never can expect the measurement to proceed systematically, and satisfactory for the purposes of the civil authorities, or free from complaints on the part of the Zemindars.

Nature of check, or *Purtall.*

The check on the total area of the village, as soon as all the fields are put together, and the totals in the Khusrah, or Field-books, added up, is easily made by a comparison with the professional area. The two operations are expected to coincide with each other within 5 per cent., though a much nearer approximation is most commonly made; and when we consider the means at the disposal of a native Ameen, it is a matter of astonishment how such a result is produced. Such is the nicety with which experienced men can bring these measurements, when rigorously watched and superintended, but only when kept in check by the simultaneous procedure of the professional survey, that thousands of villages are annually completed, differing from the true areas much less than the maximum allowance, the average difference frequently being reduced to *one* per cent. on the total area. But besides this primary test, it is essential to examine or *Purtall* a certain percentage of the fields to ascertain if *A* has received more than his proper share, or *B* less, and also to verify the crops or quality of the soil, in which lies the greater chance of the Ameen defrauding Government by describing land as second or third quality, and yielding but one crop, when it is in reality first-rate, and producing two crops annually, and on this essential investigation depends the amount of sudder jumma (revenue) likely to be collected where an assessment is to follow.

For the detection of such imposture then, *Purtall* Ameens, on suitable salaries of 15 to 20 rupees per mensem, are appointed to go to the village after the Ameen has concluded his task, and remeasure a certain number of fields at random, and describing the true produce and capabilities of the soil. It is sometimes the practice to measure a line right across the village, and to note the several distinct properties as they fall under, or intersect this line of measurement, and by this method a larger number of fields are checked than could otherwise be done. The Khusrah is likewise subjected to the personal supervision in the field of the Surveyor and his European Assistants, and to examination and check as to the accuracy of the figures in the offices. The establishment generally sanctioned for this purpose is as follows:

For 12 months. { 1 Head Moonshee at 20 to 30 rupees.
1 Naib ditto at 15.
1 Mohurrur at 10.

For 6 months. { 4 Purtall Ameens at 15 to 20 rupees.
8 Peadahs or Measurers at 3.

or one Purtall Ameen to 25 Measuring Ameens, and with such assistance the Khusrah operations ought to proceed systematically and well. Each European Surveyor and Assistant Surveyor performs this field *Imtehan*, or supervision of a certain percentage of the villages within his division, rendering a report of the results to the Deputy Superintendent after the following form, and this Purtall is filed with the misl.

Statement shewing number of Villages (measured by the Khusrah).
Tested by A. B. Surveyor.

Date of Examination.	Name of Pergunnah.	Name of Village examined.	Name of Ameen.	Khusrah Misl. Remarks.	Khusrah Map. Remarks.	General Remarks.
1847 Dec. 1st.	Sukeet...	Sudderpoor	Seyr Mull	Size of Fields, accurate; progress fair ...	Intelligible, the Fields easily identified on the ground.	This village was carefully inspected by me, and the following fields were minutely tested, Nos. 99, 98, 219, 245, 234, 244, 275, 287, 288, 292, and 291. I, however, discovered the following incidents, namely, Nos. 291 and 292, amounting to 1 beegah and 4 biswas, were inserted in the Khusrah as ratal or sandy and khakee; and the field No. 288, amounting to 18 biswas, was placed as khakee and sandy, whereas the two former fields should have been noted as chiknout abbee, and the last named field as chiknout chahee; the necessary corrections were made on the spot, and the Mootsuddee has been admonished by me against any such errors hereafter. No complaints by Zemindars—measurement completed as far as Field No. 742.

If, on a comparison of the Ameen's measurement with the professional area, or the Purtall, discrepancies are detected, the offender may be summarily punished by fine, or *in a case of fraud* against Government, the case, if made over to the Zillah Criminal Court, is punishable by fine to the extent of 200 rupees, or in default of payment to imprisonment for a period not exceeding six months. The difficulty of keeping a large body of Ameens in order must be obvious, stringent discipline is therefore absolutely necessary, and a single case made over to the Magistrate invariably instils a most wholesome awe in the rest of the establishment, and the effect produced is most advantageous.

Records how prepared and disposed of.

On the completion of the measurement of a village, the Khusrah *misl*, or *chitta*, or Field-book, as before described, is copied out fair, and the total area and abstract of details duly recorded on the fly-leaf. This document in the vernacular, together with the field map, is signed by the several proprietors concerned, any objections being fully enquired into, on representation to the Superintending Officer. After passing the test of the Purtall, and the total area of the village coinciding within the allowed limits with that of the Professional Survey, the field map is compared with the Thakbust as well as the professional map, and the whole file then made over to the Settlement Officer, duly signed and attested on every leaf, all erasures being specially accounted for. If a settlement follows, a further enquiry is instituted by the revenue authorities as to the description and quality of the soil and crops. The *khatteeawoonee*, or abstract of the number of fields appertaining to each estate, is then made out, and this forms the basis on which the assessment is levied or the Mehalwar Register is constructed in English. On the latter record being formed, with all the statistical information available from the village maps, a volume for each pergunnah is finally deposited in the Collector's office for the benefit of the public service. The vernacular files and Khusrah maps are deposited in a similar manner, and as the attainment and preparation of these documents has been laborious and expensive, so should their preservation and safe custody be equally cared for.

Objections to Ameen's proceedings.

Whatever may be the nature of the Measuring Ameen's record of the soil, or produce, Zemindars have always various objections to offer at the time of signing their agreements, and invariably press for a reduction of the estimate and a further investigation on the part of the Assessing Officer. The point is an important one, and however well a Surveyor may watch over his Ameens, it is almost an impossibility to protect effectually the

Government interests in this respect. In anticipation of a new assessment, the people have recourse to all sorts of stratagems, lands are thrown out of cultivation and allowed to run to waste, and vegetation being so rapid in India, a single season is sufficient to prevent a fair identification of the soil. Ameens likewise are notoriously venal, and an understanding is soon made with the village authorities, who are in the habit of paying a certain black mail, for every beegah, the quality of which is underrated. As detection, however, is more than probable, the promises made at the time of measurement are not always carried into effect by the Ameen, when he lodges his Khusrah, and the deception is not discovered by the Zemindar until the time of settlement arrives, and then he enters general complaints against the measurement.

The duties of Ameens are extremely irksome and laborious ; perfectly dependent on the will and pleasure of Zemindars and other lazy village authorities, for the prosecution of their daily work, and for which they are paid very insufficiently by Government, it is not surprising that they must live by other means, the remuneration therefore comes from the people of the soil. Where payment is made by contract, the Ameen must be compensated for the delay which the Zemindar deems it actually necessary to his dignity to observe, and until several petitions have been made against him, he does not dream of making a move to co-operate with, or assist the Ameen. Such a system is much to be regretted, but no endeavours, on the part of a Surveyor, can remedy it.

Obstruction to due progress.

The non-attendance and opposition of the village authorities (*Gomashtas*), agents, and people generally, and the consequent detriment to a survey, is a most serious evil. Every subterfuge is used to delay proceedings, consequently innumerable complaints are made by the Ameens, which are met with counter charges of extortion and corruption on the part of landowners, the investigation of such cases forming a very pretty item in the day's labors of a Superintending Officer. In all survey and measurement operations the very vitality and entire success of a good season's work depends, not on mere compliance only, and a tardy attention to the wants of the party, but to an *immediate* and *ready* co-operation with them. The demands for attendance *today*, when the survey approaches a certain spot, are vitiated if not responded to for a week or fortnight ; by that time the advantage is lost, and most likely the necessity no longer exists. In the Professional Survey particularly this is much felt ; scientific operations cannot stop, expensive establishments must advance, and show a certain amount of work at the end of the month,

and by the time a village authority thinks proper to do the very little that is asked of him, the survey in all probability is some miles in advance. For this cause an Ameen is tied down to a single village the greater part of the season, and it is most difficult to estimate the progress of the Khusrah, or to calculate on having the whole of the villages which have been included in the Professional, completed by the Ameens.

Attendance of landowners how enforced.

The notice of the authorities and of the Government has constantly been drawn to this subject, and a new enactment has now been published, which, though it does not go far enough for the cure of the evil, still supplies a partial remedy, which it is hoped will have some good effect. Act No. XX of 1848, "for better enforcing the attendance of proprietors and "farmers of land before Collectors of Land Revenue in the Lower "Provinces of the Bengal Presidency," authorizes the infliction of a daily fine, not exceeding in any case 50 rupees, on any farmer or proprietor who shall refuse to attend, or cause his agent to attend, when duly summoned, and the amount of such fine accruing due, from time to time, may be levied without further confirmation, by the same process as is prescribed for the recovery of arrears of revenue. Every such fine, and the amount levied, from time to time, being reported to the Commissioner of Revenue, and to whom appeal is open in the usual manner, such appeal not to prevent the levying of any fine so imposed, pending the appeal. Hitherto, before a fine could be levied, the tedious proceeding of obtaining the Commissioner's confirmation had to be gone through, and by the time this was done the business perhaps was concluded, consequently such fines were seldom if ever upheld, and the imposition became an empty form. It is to be hoped that the present law is not put into the hands of the executive for mere show or form, but that it may be brought into play effectually and instantly where necessary, so that the serious loss of time to Surveyors, and consequent increased cost and expense to Government, may in a measure be avoided. When once an example is made in a Pergunnah or District, no further difficulty is experienced, and all parties are saved a great deal of annoyance and extra labor. The Revenue Surveyors in Bengal are all vested with the powers of a Deputy Collector under Regulation IX of 1833, with a view of giving them some weight and importance in their several districts. These powers are not often required to be put in force in consequence of the presence of the Settlement Officer, but still, in cases of contempt, not involving a case of resistance, a fine may be levied, and in minor cases penal powers can be exercised under Section 21, Regulation IV of 1793,

Section 6, Regulation XII of 1825, and Clause 3, Section 23, Regulation VII of 1822, imprisonment in the civil jail for a period not exceeding six months being the alternative in default of payment of fine, under Clause 7, Section 45, Regulation XXIII of 1814.

Number of Ameens employed.

The number of Khusrah Ameens generally employed on the Bengal Surveys varies from 100 to 150 according to the strength of the Professional Establishment and the average number of villages requiring the detailed measurement. There is, however, no fixed limit, it being in the power of the Surveyor to apply as many men as the nature and progress of his work demands, and the rate of payment being solely by contract for the quantity actually measured, it is of no consequence as to the exact number entertained. It is necessary always to have plenty of these men who are able to conduct their duties systematically, and in strict accordance with the orders laid down for them, and to train and instruct others who may always be ready to be enlisted in the service. Ameens are generally to be found and are easily taught, though good and trustworthy ones are not quite so easy of attainment. Each Ameen generally is obliged to employ one or more *mohurrurs* (writers), and after a season or two, these men become experienced and fully qualified to undertake measurements themselves. Thus a full complement is always kept up, and spare men available on every emergency, and as a survey is extended from one district to another, the Ameens are taken on, with the rest of the Establishment.

In unsettled districts the proper number of Ameens necessary to keep pace with the Professional Survey also depends very much on the nature of the tenures, and is always fluctuating. If the settlement is to be made *ryutwarry*, then every separate field under a separate cultivator (ryut) must be defined, and the proceedings become very tedious and voluminous; but if the agreements are to be made only with the *Maliks*, *talookdars* or proprietors, the record of estates only is sufficient, and an Ameen can in the latter instance make infinitely greater progress. Much depends on the humour of the Zemindars; if they will readily afford assistance, the Ameen can get through his work in half the time it otherwise takes him; some Ameens will remain the whole season in a moderately sized village, whilst others will complete ten times the area in the same time. There are so many things to facilitate or retard progress, that it is next to impossible to make any effectual provision to establish an uniform rate of work, and for this reason a contract payment only can be resorted to; there is no limit to the sum drawn for

under this head, and it is not included in the fixed annual maximum. The steam, therefore, must be put on according to circumstances at the discretion of the Surveyor, so as to meet the exigencies of the operations.

Combined operations how to proceed.

The first great object is always to keep the two combined operations of Khusrah and Professional well up to or abreast of each other, it being necessary that the Khusrah should coincide with the Scientific Survey as nearly as the means employed will admit. Such a result cannot be more effectually attained than by making the two operations proceed *simultaneously* under one and the same guidance—in fact this is a *sine qua non*—and for this reason the Surveyor is the proper person to superintend and control all the proceedings relative to measurements, as in like manner the Civil Officer is, for all questions and duties of a revenue character. In the North-Western Provinces, this was invariably the case, while the quality of the soil and record of the crops rested on the responsibility of the Settlement Officer. If the operations are under different management, it is evident *simultaneous* progress cannot be expected. The Settlement Officer is either in advance or in arrears of the Professional Survey, and if the work is carried on without reference to the Survey Officer, the probable chances are that the same lands are not measured, the *(thaks)* or marks erected in the field from the lapse of time are not found, and thus discrepancies are engendered which will cause extreme difficulty and delay in reconciling; and where identity between the two operations does not exist, the matter remains a contested point between the Surveyor and Settlement Officer; the former has perfect confidence in his work, and the latter, knowing the impracticability of making Ameens remeasure, or even reinvestigate their work, believes that he is equally as near the truth—thus constant correspondence between the two offices gives rise to serious delay and incessant annoyances. On the other hand, if the Ameen is on the spot, as he invariably ought to be when the boundary of the village is professionally surveyed, and before the marks and pillars have been removed or washed away, he is at once made acquainted with the correct limits of his work, and by co-operating with the Assistant Surveyor can compare his exterior boundary, and rectify any errors which he may chance to perceive, between the marks on the ground and the Thakbust Sketch Map as furnished by the Settlement Officer. For the check on the Khusrah to be in the smallest degree effectual, it must be *prompt*, the delay of a year or a season in this respect will prove *fatal* to the value of the measurement.

By these means the records are compared *at once,* and thus by mutual assistance both parties proceed with confidence, and the first step towards accuracy is attained. The Professional Maps and Registers are all dependant on the Khusrah Returns, and by the preparation of these, in his own office, the Surveyor is enabled to complete and lodge each season's work during the recess, a point of the utmost importance to accuracy and fair progress; and on commencing a fresh field season his time and attention is not distracted by arrears and an inconvenient excess of office documents, to move about within the district. By an absence of this due and speedy comparison of the two operations, both are left in doubt and distrusted by the local Officers, and upon this bare fact, the survey of whole districts have been recommended for revision, entailing immense expense, as well as confusion in the records, and anxiety and vexation to both Zemindars and Surveyors. It is in vain to expect a large body of Ameens to be kept in check *except by the presence of a Professional Survey,* and by the knowledge that detection of misconduct is certain, through *some* of the agencies at the command of a Professional Surveyor.*

* These views and principles enunciated and acted on nearly a quarter of a century ago, are strictly adhered to and maintained as correct, after the experience gained in the interim—1874.

CHAPTER XX.

The Cost of the Khusrah.

Cost of the Khusrah.

The following Table* exhibits the general average cost of the Khusrah measurement, including the Purtal Office Establishment, and proportion of European superintendence on 15 completed Surveys in Bengal—from the year 1839 to 1849. It must be observed that where the extent measured is greatest the expense is diminished, the cost of superintendence and *Purtall* being much the same in any case, therefore the lesser area has the greater proportion of expense thrown on it. An insight into the earnings of Ameens in each season would, however, amply show, that this class of public servants do not altogether depend on the money they receive from the Government. Every Ameen is obliged to keep a (Mohurrur) writer and two men to drag his rope, besides generally a (Peadah) messenger, a (Chattah) umbrella bearer, &c

* *Table exhibiting the average Cost of Khusrah Work on Fifteen completed Districts in Behar and Bengal.*

Season completed.	Name of District.	Extent in Square Miles.	Average rate per Square Mile.			Remarks.
			Rs.	As.	P.	
1839	Jynteeah	247·30	29	15	0	Maps by Scale and Compass.
1841	Balasore..................	886·54	34	7	2	No Maps of any sort.
1841	Cuttack	1256·59	25	2	2	Ditto.
1841	Pooree	383·41	30	1	6	Ditto.
1842	Cachar and Sylhet ...	234·02	29	11	2	Maps by Scale and Compass.
1841	Tipperah	66·45	48	0	0	No Maps.
1840	Hidgelee and Tumlook	525·02	37	1	3	Ditto.
1843	Behar	562·18	35	5	2	Rough Eye-sketch Maps.
1842	Patna	1157·35	23	1	9	Ditto.
1845	Sarun	1160·00	16	14	8	Ditto.
1845	Midnapore	756·75	31	10	9	No Maps.
1848	Monghyr	843·50	21	7	5	Rough Eye-sketch Maps.
1848	Purneah	2494·00	29	7	3	Ditto.
1848	Shahabad	313·00	19	14	4	Ditto.
1849	Tirhoot	1679·25	15	10	11	Ditto.
	Area measured by Khusrah, in 15 completed Districts......	12565·00	28	8	6	General Average.

Measuring Ameens how paid.

The mode of paying Khusrah Ameens is invariably by contract; fees at the rate of about two rupees for every hundred acres of land under cultivation in Bengal are paid as soon as the measurement of the village is passed and approved of, and one rupee for the same quantity of jungle or waste. This sum includes the paper and every expense necessary for the production of a fairly written and intelligible record, which, eventually, is filed in the Collector's Office. This rate of payment, however, is somewhat higher than that observed in the North-Western Provinces, where the remuneration was not more than one rupee for a hundred acres of cultivation and eight annas for waste. The difference, however, between the two Provinces is great: in one the fields are small and complex, requiring much nicety; in the other the tenures are large, and easily and speedily measured. Ameens being paid only for work performed in the field it is their object to remain out as long as possible, but eight months out of the twelve is the utmost that can be made available for such work. During the recess therefore it is most difficult to keep this class of men in attendance at the office, and if possible miscellaneous employment should be found for them, such as the preparation of the *khatteeawoonee*, by which a subsistence allowance may be earned.*

Caste of Natives preferable for Ameens.

Hindoos of the Kyut caste are always to be preferred for this duty; and all Hindoos before Mussulmen, which latter class of men never seem able to compete either in accuracy, intelligence, or even honesty with their Hindoo brethren; it is therefore customary always to entertain men of the latter caste. Generally speaking they are respectable, well dressed and intelligent, and carry much weight with them on entering a village, assuming great consequence, and summoning the village authorities to attend them with a great deal of parade and show. The retainers of an Ameen are very considerable, and he never appears out without a bearer holding a chattah (umbrella) over his head.

In some Districts the Khusrah is carried on very badly, no sketch maps are given, and the Ameen's file, when prepared, is but a dark and doubtful document indeed. If there is any large discrepancy in the area,

* The system here described does not hold good now. Great changes have been introduced by the employment of Measuring Ameens, under the Settlement Department, and monthly salaries are now obliged to be given for such work involving additional superintendence and check over the agency employed, as well as considerable extra expense in the operations. Nothing is so cheap in India now as it was twenty years ago—1874.

it is impossible to know from what causes arising, as orders for reinvestigations in the field are seldom if ever obeyed by an Ameen, and if remeasured, produce no satisfactory result. Revenue Surveyors cannot be too particular in looking after their Khusrah work, as on its correctness depends the entire value which the local civil authorities place on the survey generally, and great discredit would attach to any Surveyor, whose Professional Survey should be revised owing to discrepancies being detected between it and the Khusrah. Ameens require the most rigorous surveillance, and without a severity and control such as European energy of character alone understands how to enforce, without, in fact, they are watched and checked with an iron hand, the utmost difficulty will be experienced in proving their measurements, and making them coincide with the professional area. Security should always be taken on the entertainment of Ameens for their good conduct and attendance, and no work is paid for until approved and passed.

To obviate as much as possible the difficulties attending the supervision of Ameens, the following rules for their management should be attended to, as far as practicable and the local peculiarities of a district will permit.

Standing Rules for the guidance of Ameens.

1st. Khusrah Ameens should be nominated to villages in such a way that they must be present when the professional boundary survey is laid down; and their personal attendance to witness this important operation ought to be insisted on, under penalty for non-compliance, a sufficient number of men being always kept up for this purpose.

2nd. Any unusual detention of the measurement papers in the hands of the Ameen after the work is done must be guarded against. As much as is done monthly, weekly, or even daily, if practicable, should be lodged in the Surveyor's Office, and constant enquiry must be made to prevent Ameens leaving the scene of their labors for their own homes, before their papers are finally submitted.

3rd. No Ameen should be employed who is unable to produce a tolerable field map (Shujreh) or sketch of his measurement, exhibiting every field and delineating the exterior boundary, and who cannot give good tangible security for his attendance and good behaviour.

4th. No Ameen to be nominated to two villages at once. As soon as the records of one are lodged in the office, it will be ample time to give him more work.

5th. Any Ameen who is constantly complaining of the conduct of Zemindars, raises an unusual number of disputes, and remains in a

village any unreasonable period, without furnishing his measurement, should be removed. Such petitions, although often well grounded, are more frequently based on motives of private pique and revenge, or to suit their own purposes, and throwing the entire responsibility on the Ameen, is the only effectual way of putting a stop to it.

6th. When an Ameen is detected in committing fraud, the case should be immediately made over to the local judicial authority. In establishments composed of 150 to 200 Ameens, the chances of detection and proof are so slight, that when a case occurs, an example of the offender is absolutely essential.

7th. Having procured the local linear measuring rod or rope of the district, every precaution should be taken to guard against the Ameen's using any other. The length of this rod or rope is to be carefully recorded in British feet and inches on the fly-leaf of *every Khusrah*, as well as on the professional village plans, and ought also to be made known by *istehar* throughout the district, no other measuring implement but an *iron chain* of the correct length, should now be on any account used.

8th. The native method of measuring and calculating areas, being limited to rectangular figures, all very irregular or uneven sided figures should be avoided as much as possible; where such shaped holdings really exist, the measurement should be divided into separate parcels, and recorded under the remarks, so that the error of the entire field may be reduced within the smallest limits. Ameens to save themselves trouble are in the habit of making their fields as large as possible.*

Irregular pieces of waste land, and watercourses, site of village, &c., running in the centre of the village circuit, may be seen on all the specimens of Shujrehs of the old surveys, but the recorded area must be far from the truth, neither is it possible to construct a map from such measurements.

9th. Each Ameen's measurement must be confined to the actual village circuit as laid down professionally and by Thakbust. All inter-mixed lands of other villages or estates found within that circuit to be included in the record under a distinct head, but all detached and

* *Definition of a field.*—" A field is a parcel of land lying in one spot in the occupation of one cultivator, held under one title, and generally known by some name in the village. The Surveyor should be careful not to show two fields as one, nor to divide one field into two. The Ameens are exceedingly apt to fall into the first of these errors, as it enables them to get over more work, and consequently to earn more in the course of the day whenever they work upon contract."—*Instructions to Settlement Officers, N. W. P., para.* 24.

distant lands, belonging to the village under measurement, not to be sought after, or cared for, such parcels and portions of land being duly taken up with the village in which they are actually situated.

10*th*. Full instructions to be embodied in a (*dustur-ool-oomul*) parwanah (written standing orders) to be given to every Ameen prior to his deputation on any measurement, and which perwanah should be copied out in the Ameen's own handwriting, to ensure the contents being, at all events, read, and as a proof that he *can* write well.

11*th*. In the fair copy of the Khusrah, no erasures or blots of ink to be permitted, and the country paper on which the document is written, should be prepared with a solution of *Tootia-Metha* and *Neem-putta*,* (articles procurable in all bazaars) as a protection against the ravages of insects. The field maps or Shujrehs should be on English paper of a durable texture, as they cannot be replaced, if lost or destroyed, without repairing to the spot to construct another.

12*th*. The fees for the performance of the measurement not to be paid until the work has been compared and found to be correct in every respect, and all the papers in which corrections and alterations may have been made have been duly replaced by fair copies, properly compared *and* attested.

13*th*. The areas of the Professional Survey to be carefully concealed from the Ameens, and native Omlah of the office, and Assistant Surveyors to be interdicted from furnishing such information either in the field or during the recess. Ameens are very liable to *make up* their total areas to agree with the professional, and by putting in infinitely small corrections over a vast number of fields, have the means of producing an approximate result.

Disposal of tracts of waste and jungle.

In many districts there will be found a superabundance of jungle and waste lands inconvenient or impracticable to measure by Khusrah, and which also, on the score of expense, it is unadvisable to permit the Ameen to interfere with. When a village circuit contains a very large proportion of such land, the existence of which is always ascertained by the Professional Boundary Surveyor, the cultivated portion of the village should be divided off into a separate circuit by the interior detail Surveyor, so as to permit the area to be calculated by triangulation on the map, and only so much given to the Ameen, for a comparison of whose work, therefore,

* "Tootia," Sulphate of Copper, Blue Stone, "Metha," Fenugreek (Trigonella Fœnum-græcum). "Neem Putta," Leaf of the Neem Tree (Melia Semper Virens).

a distinct area is found by the professional operations. The jungle thus forming a circuit of itself, its area can either be added to the Khusrah *misl* in the aggregate from the Professional Survey, or a note can be made by the Ameen that it has been omitted in his proceedings. By this method considerable expense is saved in the Khusrah operations, and the accuracy of the area of the cultivated portion, really measured by an Ameen, is not vitiated by the insertion of the area of such pieces of waste and jungle, which it is well known a native Ameen *cannot*, and will not actually measure in the field, but invariably enters it by guess. The small additional labor with the Professional Survey is therefore, in all respects, the preferable course to pursue. Of all things forged measurement papers are the most to be deprecated and guarded against; whilst an offence of this nature should always be visited with the severest punishment, the temptation should never be put in an Ameen's way, and if a large portion of a village circuit is reported to consist of jungle or waste land, immediate steps should be taken to relieve him of the measurement of it. The difficulty of obtaining any assistance from Zemindars to clear jungle land is quite sufficient excuse for the Ameen to make, and it is generally set forth pretty strongly, and not without justice. On the other hand, where merely small patches of waste are scattered about a village circuit, intervening with the cultivated parts, they should invariably be included in the Khusrah, for the sake of the comparison of the total area of the village with the professional, as without this check it is most unlikely that the Ameen will be at all cautious, or be swayed by a wholesome dread of detection in any malpractices he may have in contemplation.

CHAPTER XXI.

A NEW AND IMPROVED MODE OF CONDUCTING THE KHUSRAH.

HAVING given the usual mode of native measurements as carried on throughout the North-Western Provinces and Bengal, we proceed to notice an improved and very superior system introduced of late years in some of the Eastern Districts, and which, for accuracy and general usefulness, far surpasses the rude and antiquated specimens which in our own experience we have seen and had good cause to deplore.

It is obvious that a heavy file of papers in the vernacular, containing the detailed specifications of a village, comprising, perhaps, 1,000 to 1,500 fields, without a map, or merely a rough ideal sketch made without reference to scale and compass, must at the best be a doubtful document, and in spite of the strictest Purtall, or check in the field, *may* contain many inaccuracies, and elude the vigilance of office examiners. To obviate such doubts and uncertainties, and to place this native process of measuring land on a better comparison with English conceived ideas, the Ameens in the districts of Sylhet, Jynteah and Cachar have been taught the use of the compass, and to conduct their measurements, and enter them in the field-book in such a way that a *bonâ fide* map, by scale and protractor, may be made from it, not only by themselves, but by any other person unacquainted with the field duties, at any subsequent time.

The class of natives usually employed as Ameens in India are proverbially shrewd, intelligent men, and have a good *eye* for surveying, and many rise to be practical Surveyors, and use even a Theodolite with facility and correctness. The art, therefore, of taking a bearing with the very simple compass which is here described is very speedily learnt, and an instrument quite sufficient for the purpose may be made up in any bazaar in India for about three or four rupees.

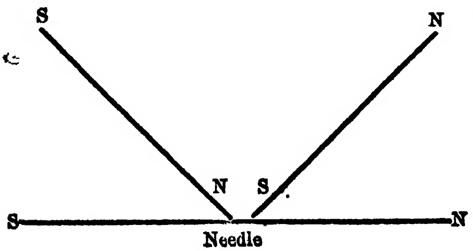
The diagram, page 53, represents an instrument of similar construction, an open round box made of brass, from 3 to 5 inches in diameter, and half an inch deep, with two upright pieces screwed on perpendicularly, and exactly opposite to each other. In the centre of the box a pivot of steel, finely pointed, is fixed, on which the magnetic needle freely revolves. The needle must be made of steel, the north end being well distinguished by an arrow, and a small brass cap of a conical form (agates not being procurable) in the centre, to rest on the pivot. Inside

the compass box a slight ledge is necessary to hold the glass, over which a thin ring of brass, removable at pleasure, fits tightly, to secure it from falling off. Underneath the compass box a common socket of about an inch long is fixed, for fitting on to the tripod stand, on the top of which it must turn freely, with a small clamp screw to prevent the instrument falling off when carried from one station to another.

A paper dial, divided into degrees from 1° to 360°, which is easily constructed with a common protractor, with the figures marked in the *vernacular* character, is fixed to the bottom of the compass box, care being taken to make the division of 360° coincide exactly with the hair sight vane, and consequently 180° with the eye vane. The degrees must be numbered round the circle from zero towards the left, and the cardinal points inverted, the result of which is, that, in turning the compass in any direction, the figures underneath the north end of the needle indicate the correct magnetic bearing of the object, and the observer has only to read off.

The needle must be properly magnetised,* for which purpose a common magnet, which may be procurable in Calcutta for a few rupees, ought to be provided by the Deputy Superintendent, and this will enable him to keep as many needles as he likes in good order; care, however, should

* Strong Standard Magnetic Bars are now obtainable from the Government Mathematical Instrument Depôt, Calcutta, for the use of every survey party, and these can be used, in most ordinary cases, to restore the magnetic power of compass needles by observing the following instructions. Place the *needle* to be remagnetised on a block of wood in which a hole should be cut to receive the brass centre piece of the needle. Now take the magnetic bars, one in each hand, keeping the north and south poles opposed to each other, slope the bars inward to any convenient angle and press the ends down firmly on the needle near the centre, without permitting any contact of the *bars* and taking care (*vide diagram*) to place the south pole of one bar towards the North half side of the needle, and the north pole of the other bar towards the South half of the needle, or in other words, place *negative* end of bar to *positive* side of needle, and *vice versâ*. Now draw the bars firmly from the centre towards the ends of the needle (in opposite directions), lift the bars clear of the ends of the needle, and return to the centre each time continuing the operation as long as may be necessary. Magnetic compasses, when not in use, should always be stored in such a way as to allow all the needles to remain north and south, and not be placed promiscuously when in contact with, or near each other.



be taken never to entrust this magnet in the hands of a native, who, being unacquainted with its properties, would be sure to employ the negative and positive points to the wrong end of the needle, and thus render the compass unfit for all practical purposes, and likewise injure the magnet.*

A simple tripod stand of any seasoned wood is also easily made up by any bazaar carpenter. The circular pieces of glass to fit over the compass box, may be difficult sometimes to obtain, glaziers and diamonds not being plentiful in India, but by sending a paper pattern to the nearest large town or city, a supply can generally be found, and spare glasses should always be kept ready to replace breakages.†

It must not, however, be imagined that this roughly-constructed instrument above described is the best that can be found, or that by proper application through the Government authorities better ones are not to be had. In the Government Mathematical Instrument-Maker's Department in Calcutta, the best workmanship and best materials are procurable, and surveying compasses are made up, fit for this purpose, equal to any that come from England. These, however, are comparatively expensive articles, and where such numbers are required, economy should be considered. It is, moreover, the object of these pages to show the readiest and easiest practical method of turning the means at hand to the best account. Surveyors should never be at a loss for an expedient, and situated as they are frequently, and indeed generally, in unknown parts of this vast empire, an ingenious mind, ever ready to make shift with such advantages as present themselves, will be the surest road to success.

Being provided with a compass of this simple construction, and having learnt the manner of reading off and taking bearings, the Ameen commences to measure the *exterior* fields of the village,—that is, all the fields extending round the boundary—as shown in the accompanying map, Plate XV. For each field two bearings are taken, one for the length and

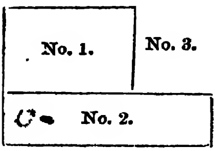
* On the first introduction of this system, the compasses were nothing more than mere *blocks of wood*, hollowed out to receive the needle with brass uprights for sights, and these rough instruments costing a mere trifle (less than a rupee), did effectual service for some time, until they were superseded by the brass and more durable ones above described.

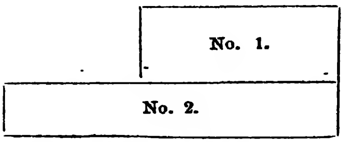
† A very simple expedient for cutting glass, though perhaps but little known, may here be recorded with advantage. By taking any piece of glass, such as a broken pane out of a window, and a pair of good sized scissors, and placing both hands well under cold water, in a large *chillumchee* or brass basin, the glass may be cut round and round until the proper size is obtained. The only care that is requisite, is to keep both the glass and the scissors *completely under the water*, and to clip the glass very gradually, so as not to cut off too large a piece at a time. In this way many compasses have been rendered serviceable out in the jungles, and Ameens kept at their work, when otherwise delay and inconvenience must have arisen.

another for the breadth, with occasionally a diagonal observation for the better connecting link between the several fields, and to ensure greater accuracy in the mapping, and also to enable the observer to take all his bearings from one station. In the Khusrah Field-book separate columns are given for this "*station bearing*" and "*distance*," as it is called, by which means it is not confused with the quantities required as multipliers for the contents of a field. The bearings are inserted in the following form *(see end of Chapter)* which only differs slightly from the form before given at page 368.

For the boundary work, columns 11 and 12, as well as 7 and 9, are therefore merely required for the due protraction of the fields on the map, whilst 8 and 10, in addition to their use for this purpose, are alone required for the area of the fields to give the contents for column 13. For the record of the measurement of the fields in the interior of the circuit, columns 7, 9, 11 and 12 are entirely omitted, the fields being put together from their respective linear values.

In the usual method of measurement, each field is merely recorded as lying to the north, south, east or west of the preceding ones, and frequently even this is omitted, but this is not sufficient to ensure a large number of fields plotting accurately within a circuit laid down by compass. Although the fields are for the most part rectangular, still they are to be found of various admeasurements, and to enable the map to be made by any other person than the Ameen himself, who possesses a local knowledge of the disposition of the fields, and sketches them in on his map at the time, it is essential to have a defined *starting point* for the measurement of each field: thus it is recorded in the Khusrah that field No. 2 commences from the *south-west corner* of No. 1, and No. 3, from the *north-east corner* of No. 2, and in this expression of the *corner starting point* lies the whole secret of the system. If this is not observed, the relative position of Nos. 1 and 2 fields may be inverted as shown in the diagram, and the whole disposition of the fields of the entire village thrown out: in fact, the Khusrah Field-book defies all attempts to reduce it to an intelligible map.





The *circuit* having thus been effected, all the interior fields are laid down merely with the rod or rope in the usual way, but still preserving

the *corner* system, without any further aid from the compass, and by plotting the circuit of exterior fields according to their magnetic bearings, the interior details are found to fit in very accurately indeed. The first or rough plot of course will always show defects, but all errors are thus recorded on the first protraction, as in Plate XV, and brought to the Ameen's notice, and after he has put them to rights by reinvestigation in the field and filed his answer, the necessary corrections are made on the map, which will then bear the closest comparison with the professional one, as regards the inflections of the boundary, the distribution of details of cultivation, waste, nullahs and roads, &c., as well as area; and it is by these means that a Surveyor is enabled to check with the utmost nicety all inaccuracies in the Khusrah measurement, and at the same time satisfy himself that the large mass of vernacular papers brought in by his Ameens are trustworthy, and *bonâ fide* contain what they pretend to do.

It must not be supposed that the Ameen is able to make the bearings of large village circuits close without error by such means, the enormous number of observations, to say nothing of the very roughly constructed compass, and rude measuring implements, forbid this. The village is subdivided into convenient small circuits of 150 to 200 acres, round each of which the bearings are taken, and thus the error in filling in the very large number of fields, is diminished and compressed within reasonable limits.

One very desirable object in this method is to place the Khusrah Field-book in such a form, that any other person, who may have had no local knowledge and no intercourse with the Ameens, is capable of protracting the fields and constructing the map, by which every inaccuracy in the field-book is brought to light and corrected. Thus not only the bearings of each circuit and the several linear measurements are tested, but many other discrepancies regarding quality, area, possession, &c., are prominently brought to notice and at once rectified.

The circuit and the fields in the interior of the circuit must be protracted *separately* in the first instance, as from inaccuracies of the circuit bearings and various other defects of measurement and notation of the cardinal points in the Khusrah Field-book they cannot be expected to fit in precisely, but after all the defects both of circuit and interior field measurement have been adjusted, the fair map is then put together. A proportional scale, 3 or 4 times larger than that used for the professional maps, is employed, either of 12 or 16 inches to the mile (equal to 5 chains to the inch), which is large enough to show the smallest holdings. The Plate XV exhibits the precise method of constructing

this Khusrah map, and the explanatory notes thereon account for each step in the work. The map when completed has the several items of waste, nullahs, roads, village site, &c., colored, and shows the limits and extent of each interlaced and separate mehal. It then bears a perfect resemblance to the map of the Professional Survey with which it is compared, and identified in all its particulars, and by means of a pair of proportional compasses, the most satisfactory check is established, and no doubt can then exist of the true boundary having been adopted by both parties. By the same means also, the interior details may be taken from the Khusrah map, and reduced on to the professional one with sufficient accuracy; and thus save a very considerable expense for carrying on this part of the work by professional means.

The fair colored Khusrah map may either be attached to the field-book, or formed up into *Pergunahwarry* or separate records for each Pergunnah-volumes, for better preservation, and then made over to the Civil Authority, and by the aid of such records, not only is a settlement effected with great facility and convenience, but subsequent suits in the Civil Courts are rendered at once intelligible and easy of adjustment. In fact, in a country where the settlement is made ryutwarry, it is difficult to understand how the assessment can be fairly levied, and the rights of the numberless cultivators preserved, without something of this kind.

The expense of this method of Khusrah must next be considered. The work is done by contract, and the rates are nearly the same, as in other districts, varying from 2 rupees 8 annas to 2 rupees 12 annas per 100 acres for cultivated land, and 12 annas to 1 rupee for the same quantity of waste, and when the extra labor of the system, and the very small size of the tenures in the Bengal districts is considered, this remuneration must be acknowledged to be very inadequate. The only difference consists in the salaries of the " Nucksha Nuvees, " or mappers, who are employed in the office and receive from 10 to 20 rupees per mensem, but with this extra expense, the general average of the Khusrah work thus performed in Jynteah and Sylhet, as exhibited in the Table in page 379, forms a very good comparison with the 15 districts therein enumerated; in fact, the cost is lower than six of these districts, in none of which do the Civil Authorities possess any authentic Khusrah map, beyond the common rough sketch made by the Ameen himself in the field, and who in so doing, of course, takes care to make up his map, whether his field-book is right or wrong.

The expense of the "*Nucksha Nuvees,*" Native Draftsmen, also is balanced in a great measure by the duties they perform as Purtallers, and the good

and efficient aid they render in this way more than compensates the amount of their salaries. A practised Nucksha Nuvees will protract 150 fields in a day, and this quantity has generally been done where the holdings were particularly intricate and small, but with inexperienced hands and beginners 100 fields is as much as can reasonably be expected per diem.

The great difficulty in placing this system on an efficient footing is the procurement of qualified Ameens and Nucksha Nuvees. But Ameens who are expert, as the generality of them undoubtedly are, and have been shown to be capable of producing eye-sketches of their measurements with wonderful accuracy and approach to the identical shape of the village, may soon be taught. The most intelligent Ameens should be first instructed in the use of the compass, and to construct their own maps on any given scale. After a few good men become expert (and which they soon will do if the Surveyor *personally* labors in their behalf, and is not above teaching them himself), others may be placed under them, and thus in a single season, by a little judicious management, a very fair beginning may be made. If each district Surveyor obtained the services of even *one* experienced Nucksha Nuvees, the method would soon be introduced, and made perfectly intelligible to the understandings of Ameens of the commonest calibre. The adoption of this system on all the surveys in Bengal, it is believed, is now insisted on by the authorities.

Regarding the *advantages* of this sytem of Khusrah, no reasonable doubt can be entertained, combining as it does every property of the old zemindary method, with the addition of a little English science, by which a nearer approach to accuracy is attainable, and deception and fraud detected. The rudest people of a district can easily understand the Ameen's proceedings and accompany him, for the purpose of taking a copy of the measurement of the fields, even if the addition of the bearing be unintelligible. In Jynteah and Cachar, where it was first introduced, the inhabitants were alike unused to British rule or customs, but in no instance was the progress of the Ameens interrupted by violence or pretended dislike to the operations.

These advantages may be summed up in the following manner :—

1st.—The admirable check and comparison afforded and consequent superior accuracy of the work.

2nd.—The ability of any second or third party ignorant of the locality, and without connivance with the measuring Ameen, or help of any sketch or map, to produce a fair protraction from the misl or file.

3rd.—The thorough insight thereby given to the voluminous Khusrah misl, and immediate detection of all errors, clerical or venal.

4th.—The great benefit to the Surveyor or Superintending Officer, who thus obtains the utmost confidence in his work, and is saved infinite trouble, annoyance and doubt.

5th.—The value to the Government in possessing a really useful and permanent record, combining the qualities of the professional map, with the addition of the minutest detailed specifications of property in the village, fit for every purpose both fiscal and judicial.

6th.—Its comparatively inexpensive cost when viewed with the lasting value of its results.

The great desideratum of a superior method of Khusrah than what is at present carried on in most districts, cannot be too strongly impressed on the notice of Surveyors. The benefit to the State, as well as the great comfort to himself in having a fair and intelligible measurement record, which can be rendered useful hereafter and amenable to scrutiny and check at the time, must be obvious to any person who has had experience in such matters. In Bengal especially, where it is almost an impossibility to show the different estates on the maps of the Professional Survey, it is absolutely essential to produce Khusrah maps on such an extended scale, as we have above described, which will delineate every estate on the rent roll, however intermixed or confused. The system that we are advocating is the only one applicable for such purposes; it is at once *efficient* and *economical*, and is eminently calculated to effect every object, if properly conducted. It also affords the readiest means of carrying out the provisions of Act No. IX of 1847, "*regarding the Assessment of Lands gained from the Sea or from Rivers by alluvion or dereliction within the Provinces of Bengal, Behar and Orissa.*"*

It may be remarked, that if this system is so superior and trustworthy, the fact of its wider diffusion not having extended to other districts, is a matter of surprise. This must undoubtedly be acknowledged, and it is to be regretted that improvements in the Khusrah have not been long ere this introduced into every survey. The principle here spoken of has been made no secret on the part of those engaged in its practical application. In some Revenue Surveys the Khusrah is too apt to be regarded as a secondary and unimportant branch, and all improvements and inno-

* Clause 3. "And it is hereby enacted, that within the said Provinces it shall be lawful for the Government of Bengal in all districts or parts of districts of which a Revenue Survey may have been or may hereafter be completed and approved by Government, to direct from time to time, *whenever ten years from the approval of any such survey shall have expired*, a new survey of lands on the Banks of Rivers and on the shores of the sea, in order to ascertain the changes that may have taken place since the date of the last previous survey, and to cause new maps to be made according to such new survey."

vations require great energy and perseverance, as well as other persuasive and conciliatory qualities on the part of the Surveyor, whose time and attention is well occupied by the scientific portion of his duties. It should, however, be remembered that the Khusrah forms the basis of all the revenue proceedings, and which alone the local authorities bring into practical use, and that the result is satisfactory and creditable to the parties employed, in proportion as the people of a district enter into their agreements, and pay up regularly the jumma assessed. A good settlement, made without much complaint and opposition on the part of land-owners, assuredly reflects *great credit* on a Surveyor, who will thus obtain his reward for any trouble or pains the Khusrah may have cost him.*

* The above description of the aboriginal method of conducting native measurements of the land is in strict conformity with the practice and custom of those days and when this book was first published, and is only intended as a guide to such rough description of work for the benefit of non-professional persons who so often in this country have to superintend or conduct land measurements for various objects. But the professional "CADASTRAL or *field* by *field*" survey on a scale of 16 inches to the mile, or 5 Gunters chains to the inch, or 1: 3960 recently introduced for the resurvey of the North-West Provinces, to which reference is made at page 206, is a scientific and perfect system of conducting "*field*" measurements by which the correct external limits of each *field*, or plot owned by separate cultivators, and detailed specification of the soil and crop, together with a topographical delineation of the ground, are obtained at the same time, but it would not be practicable to conduct "Khusrah" measurements on the same system or any modification of it without efficient Professional European Agency.

It is based on the circuit traverse system by Theodolite and Chain described in Chapters VI to XIV, pages 222 to 321, the *main* and village or *sub-circuits* being further subdivided by minor traverses or chain lines, emanating from and closing on Theodolite Stations, or else commencing from three or more of the village traverse sub-circuit Theodolite Stations, and meeting in a central point within the village sub-circuit, thus splitting the village periphery into several small triangles and trapezi, the sides of which are carefully chained over, and all boundaries of *fields* and features of the ground across which these chain lines run are noted in the field-book and field sketch plan; offsets along the chain line are also taken to ascertain the length, breadth or diagonals of *fields*, as may be necessary and as is fully described in Chapter II, pages 195 to 206, "On Surveying by the Chain only."

To ensure the greatest possible accuracy in these *cadastral* measurements, at the very least ten per cent. of the *fields* in every village are remeasured independently, and *check* traverse *(purtal)* lines, by chain, are run across at regular intervals through the lands of each village. The greatest difference allowed between the area of a village, as obtained by traverse circuit and the aggregate area of *fields*, is one per cent.

Chapter II, pages 195 to 206, "On Surveying by the Chain only." is strongly recommended to the notice of superintendents of settlement surveys. If to the system of chain surveying as therein described, they could add compass bearings of the lines of the several large triangles, taken at the principal stations of the triangulation, a very perfect and accurate "*Khusrah*" map would be obtained, which would compare favorably with the professional survey. As the value of land in India increases, so it is essential to improve the record of rights throughout the country, and to exchange old and obsolete methods of measurements for more rigorous and trustworthy ones.

FORM OF KHUSRAH FIELD-BOOK (No. 1,—COMPASS JURREEB).

Mouza Dollycrmutty, Pergunnah Chottool, District Jynteah.

* This Village is measured with a Bamboo Null of 16 Dustedarree Haths, or 25 ft. $1\frac{1}{16}$ ins. English measure. By Rajkishur Khur, Ameen.

No. of Stations.	Number of Dagh or Field and its Starting Place.	Number and Name of Talook or Towje.	Former nature of Tenure.	Name of Merasdar or Proprietor.	Name of Jotedar or Cultivator.	Bearing of Length.	Measure of Length in Nulls.	Bearing of Breadth.	Measure of Breadth in Nulls.	Station Bearing.	Station Distance in Nulls.	Contents.	Description of Soil.	Crops.
1.	2.	3.	4.	5.	6.	7.	8.	9.	10	11.	12.	13. K.K.P.	14.	15.
1	No. 1. Commenced east of Oondrakassee Nuddee and Mouza Seebnuggur.	No. 212 Surpuddee Sickdar.	In the Rajah's time, this was Ryuttee land.	Jattrapal, Son of Sonarampal.	The Possessor ..	186°	W. 9 E. 10 $9\frac{1}{2}$	120°	N. $1\frac{1}{2}$ S. $1\frac{1}{2}$ $1\frac{1}{2}$	186°	9	0 0 2	1st Quality.	Bheet, or Garden.
2	0	0	0	0	0	0	0	0	0	120	$1\frac{1}{2}$	0		
3	No. 2. North of same Nuddee, commenced from south-east corner of No. 1 Field.	Ditto ..	Ditto ..	Rampal, Son of Kettee Mundul.	Ditto ..	108	N. 5 S. 5 5	12	E. 2 W. 1 $1\frac{1}{2}$	108	5	0 0 $1\frac{1}{2}$	Ditto ..	Ditto.
4	No. 3. North of same Nuddee, commenced from south-east corner of No. 2.	Ditto ..	Ditto ..	Jattrapal, Son of Sonarampal.	Ditto ..	97	N. 7 S. 7 7	10	E. 2 W. 2 2	97	7	0 1 1	Ditto ..	Ditto.
5	No. 4. North of same Nuddee, commenced from south-east corner of No. 3.	Ditto ..	Ditto ..	Ditto ..	Ditto ..	97	N. 7 S. 7 7	11	E. $2\frac{1}{4}$ W. $2\frac{1}{4}$ $2\frac{1}{4}$	97	7	1 $1\frac{1}{4}$	Waste ..	Gopaut.

CHAPTER XXII.

THE LOCAL LAND MEASURES, AND MODE OF REDUCING LINEAR INTO SQUARE MEASURE.

THE calculation of the true land or square measure of the district should be made with the greatest care, and too much precaution cannot be observed in personally comparing the standard cubit or "hath" usually given by the Collector of a district. On the relative value of the beegah with the British acre, depends the subsequent confirmation or rejection of all the native measurements; therefore unless accurate Tables are formed at the commencement of operations, the utmost confusion in carrying on the office duties is likely to arise. It will then be the first duty of the Surveyor to apply for the standard *cubit, guz, luggee, hath, jurreeb, russee, rod, chain,* or whatever may be the name of the linear measuring implement in use, and ascertain what number of such lengths constitute the *side* of a beegah. The value of the local standard, if such a thing exists, after being very carefully measured *several times over,* must be recorded in British feet and inches; with these two data the number of square yards in a beegah is deduced, and from thence the number of acres, roods, poles, &c. This having once been established, two Tables should immediately be drawn out, one of *beegahs* converted into *acres,* and the other of *acres* into *beegahs.* These will save an infinity of trouble, and indeed are absolutely indispensable for the ready understanding of both Europeans and natives in a Survey Office, and to prevent error in frequently comparing the areas of the two operations.

Supposing the length of a rod furnished by the Collector of a district to be 25 feet 1·92 inches, as ascertained by repeated trials, and the beegah to be a rectangle whose sides are 28 and 12 of these rods respectively, we shall then have 28 × 12 = 336 square rods in a beegah, and 25 feet 1·92 inches × 12 = 301·92, which squared, gives 91155·7864 square inches in one rod. This multiplied by 336, the number of square rods in a beegah, gives 30628344·2304, the number of square inches in a beegah, which divided by 1296, the number of square inches in a square yard, gives 23632·9816 square yards or 4·8828 acres, equal to 4 acres, 3 roods, 21 poles, 8 yards. Again, if the russee is found to be 80 yards exactly, and the beegah side is one russee,

then the beegah will be 80 × 80, equals 6400 square yards, and if $\overset{\text{sq. yds.}}{4840} : \overset{\text{acre.}}{1} :: \overset{\text{sq. yds.}}{6400} : \overset{\text{acres.}}{1{\cdot}322314}$, the value of the beegah is therefore $\overset{\text{acres.}}{1{\cdot}322314}$ or $\overset{\text{acre.}}{1}\ \overset{\text{r.}}{1}\ \overset{\text{p.}}{11}\ \overset{\text{sq. yds.}}{27{\cdot}60}$.

In the North-Western Provinces, the beegah does not vary much, the *Agra* beegah of 2756¼ square yards, the beegah *side* of 52 yards, 1 foot, 6 inches, is common to many other districts such as Muttra, Allyghur, Mynpooree, Etawah, Furruckabad, &c. The *Delhi* Province beegah contains 3025 square yards, or five eighths of an acre (3 roods 5 perches) of the standard *Ilahy* guz assumed at 33 inches, the beegah *side* being 60 guz or 165 feet or 55 yards, and this is also common to the Umballa, Khytul, Loodhianah and Ferozepore Districts, the Jullundur Dooab, as well as to the greater part of Behar. The best information extant on this subject from Prinsep's Useful Tables, is given in the notes,*

* The *Ilahy guz* of AKBER was intended to supersede the multiplicity of measures in use in the 16th century, and in a great degree it still maintains its position as the standard of the Upper Provinces. In general, however, different measures are employed in each trade, and the cloth merchant in particular has a distinct guz of his own. Thus the cloth guz has assimilated in many places to two haths, or one yard; and the frequent employment of English tape-measure, as well as carpenter's two-feet rules, will ere long confirm the adoption of the British standard to the exclusion of the native system, for the linear measure of articles in the bazaar.

The true length of the *Ilahy guz* became a subject of zealous investigation by Mr. NEWNHAM, Collector of Furukhabad, and Major HODGSON, Surveyor-General, in the year 1824, during the progress of the Great Revenue Survey of the Western Provinces, when it was found to be the basis of all the records of land measurements and rents of Upper India. As might have been expected, no data could be found for fixing the standard of AKBER with perfect accuracy; but every comparison concurred in placing it between the limits of 30 and 35 English inches; and the great majority of actual measures of land in Rohilkhund, Delhi, Agra, &c., brought it nearly to an average of 33 inches. Mr. DUNCAN, in the Settlement of the Benares Province in 1795, had assumed 33·6 inches to the Ilahy guz, on the authority, it may be presumed, of standards in existence in the city, making the beegah = 3136 square yards.

The results of the different modes of determination resorted to in 1824-5, so characteristic of the rude but ingenious contrivances of the natives, are curious and worthy of being recorded. Major HODGSON made the length of the *Illahy guz*

	Inches
From the average measurement of 76 men's fingers' breadths	= 31·55
From the average size of the marble slabs in the pavement of the Taj at Agra (said to be each a *Shahjehany guz* of 42 fingers?)	= 33·58
From the side of the reservoir at the same place, called 24 guz	= 32·54
From the circuit of the whole terrace, 532 guz?	= 35·80
Mr. NEWNHAM, from the average size of 14 char-yaree rupees, supposed to be each one finger's breadth, makes it	= 29·20
From the testimony of inhabitants of Furukhabad	= 31·50
From statement in the Ayeen Akbery, of the weight of the cubic guz of 72 kinds of timber (this would require a knowledge of the weights)	

but from all we are able to gather, we incline to the belief that the *general standard* spoken of by Prinsep was never regularly introduced into the Revenue Survey of the North-Western Provinces. In addition to the two beegahs already noticed, the Benares and Ghazeepore beegah of 3136 square yards was actually in use. In Bengal, however, the value of the beegah varies in every district, frequently in every Pergunnah, and occasionally in every estate or village within the same Pergunnah. In the "Tables of Land Measure, published by order of the Sudder Board of Revenue, Lower Provinces, in 1840," there will be found no less than 218 different beegahs, or other local measures of various denominations, in 38 districts, varying in size from one rood to 50 acres. In the single district of Midnapore, there are 53 different land measures, in Jessore 20, and in Rungpore 15, and in many districts there are at least from 6 to 10 different sorts. In the Province of Orissa, the number of measuring rods formerly were too numerous to detail, but

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	Inches.
Mr. HALHED, from average measurement of 246 barley corns	= 31·84
From ½ sum of diameters of 40 Munsooree pice	= 32·02
From ⅓ of 4 human cubits measured on a string	= 33·70
From average of copper wires returned by Tehseeldars of Moradabad as counterparts of the actual measures from which their beegahs were formed	= 33·50
Mr. DUNCAN, as above noticed, assumed the *Illahy guz* at Benares	= 33·60
In Bareilly, Boolundshuhr, Agra, as in the following table, it is	= 32·50

It is natural to suppose that the guz adopted for measuring the land should vary on the side of excess, and probably all the above, thus derived, are too long. The Western Revenue Board, thinking so many discrepancies irreconcilable, suggested that the settlements should everywhere be made in the local beegah, the Surveyors merely noting the *actual value of the Ilahy guz in each village*, and entering the measurement also in acres; but the Government wisely determined rather to select a general standard, which should meet as far as possible the existing circumstances of the country. Thus the further prosecution of the theoretical question was abandoned, and an arbitrary value of the *Ilahy guz* was assumed at 33 inches, which was in 1825-6 ordered to be introduced in all the Revenue Survey records, with a note of the local variation therefrom on the village maps, as well as a memorandum of the measure in English acres. Mr. Secretary MACKENZIE thus describes the convenience which the adoption of this standard (sanctioned at first only as an experiment and liable to reconsideration) would afford in comparisons with English measures.

"Taking the *jurreeb* (side of the square *beegah*) at 60 *gunteks*, or 60 *guz*, the *beegah* will be 3600 square guz, or 3025 square yards, or five-eighths of an English acre (3 roods, 5 perches). The *jurreeb* will be equal to 5 chains of 11 yards, each chain being 4 *gunteks*. In those places where the *jurreeb* is assumed at 54 guz square, it would equal 4½ chains, giving 2450¼ square yards (or 2 roods, 10 perches). In either case the conversion from one to another would be simple, and the connection between the operations of the Surveyors and the measurements of the Revenue Officers would be easily perceived."

This convenient beegah of 3600 square *Illahy guz*, or 3025 square yards, or five-eighths of an acre, may be now called the standard of the Upper Provinces. It is established also at Patna, and has been introduced in the settlements of the Sagur and Nerbudda territories.

CHAPTER XXII.]

through the interference of the local authorities, one standard of 4840 square yards, equal to the British acre, was adopted, on the first introduction of survey operations, and carried throughout the three districts of Cuttack, Pooree and Balasore, without opposition or dislike on the part of the people. The value of the measuring rod or *Puddika* being 10·4355 feet or 10 feet $5\frac{11}{50}$ inches, and the side of the acre 20 of such rods.

It would appear that the returns furnished to the Sudder Board of Revenue of the various land measures, are partly erroneous in some districts, the survey of which has been completed, the beegah actually used differing with the one recorded in the Tables. In some of the local offices the standard measure is simply a matter of tradition, and when applied for, the Nazir of the Court is directed to report on the correct length of the hath or luggee—this he does with the utmost simplicity by holding up his own arm, pointing from the elbow to the tip of the little finger, sometimes adding that as he is a small made man, one, two, or four, fingers' breadth must be added on. The Collector on this gives an order for a rooboocarry to be sent to the Surveyor Sahib, to the purport of the standard in use in his district being "one hath and four fingers," and the luggee or russee being so many of such lengths. This vague and uncertain information, however, should not satisfy a Surveyor. Such data for such a purpose are manifestly absurd, and yet it is daily in practice in many districts in the Lower Provinces where Ameens are sent out *to investigate* into special cases connected with the Civil and Judicial Courts. If a Surveyor is unable to obtain some sort of definite length for the standard measure, it should be his duty to fix and determine it, in personal communication with the Collector of Revenue. In some districts, an iron bar, or rod, is lodged in the Collectory, indicative of the value of the cubit or hath, in which case of course the Surveyor has only to compare its length very carefully as before remarked. On the completion of a survey, the identical measuring rod or chain should be lodged with the Collector of a district, and its exact length fully reported on for future reference. It is also most necessary to furnish a copy of the Table of Land Measure as used in the survey, and without this precaution is taken, the probable chances are that the local authorities will adopt some other Measure in any subsequent investigations which they may have to make in the field, the result of which must of course be unfavourable to the records of the survey on a comparison being instituted.

Zemindars and other Village Agents have always a good deal of objection to make regarding the length of the measuring rod, and are most persevering in their efforts to prove that the one about to be brought into

use is too long or too short, or different to what the former measurement was conducted with. The object, generally, is to make the beegah larger than it ought to be, when in the event of assessment the Government Revenue may fall lighter.

The following Tables of some of the chief beegahs in use in the Upper and Lower Provinces will prove useful, and exemplify the remarks in the previous pages on the subject. From the decimal of an acre, the smaller denominations are easily obtained by multiplying by 4 and 40, and in the same way with the decimal of a beegah, by multiplying by whatever the local land measure dictates :

	The Agra Beegah.					*The Delhi Beegah.*			
	Acres.	Beegahs.	Beegahs.	Acres.		Acres.	Beegahs.	Beegahs.	Acres.
2756·25 Square Yards.	1	1·7560	1	0·5694	3025 Square Yards.	1	1·600	1	0·625
	2	3·5120	2	1·1389		2	3·200	2	1·250
	3	5·2680	3	1·7084		3	4·800	3	1·875
	4	7·0240	4	2·2778		4	6·400	4	2·500
	5	8·7800	5	2·8473		5	8·000	5	3·125
	6	10·5360	6	3·4168		6	9·600	6	3·750
	7	12·2920	7	3·9863		7	11·200	7	4·375
	8	14·0480	8	4·5557		8	12·800	8	5·000
	9	15·8040	9	5·1252		9	14·400	9	5·625
	10	17·5600	10	5·6946		10	16·000	10	6·250
	11	19·3161	11	6·2642		11	17·600	11	6·875

The beegah of 3025 square yards prevails also in the Districts of Patna, Shahabad, Sarun, Bhaugulpore and Monghyr. The beegah of 3136 square yards is in common use, and peculiar to the Benares and Ghazeepore Districts.

	The Benares Beegah.			
	Acres.	Beegahs.	Beegahs.	Acres.
3136 Square Yards.	1	1·5133	1	0·6479
	2	3·0867	2	1·2958
	3	4·6300	3	1·9438
	4	6·1733	4	2·5917
	5	7·7168	5	3·2396
	6	9·2601	6	3·8876
	7	10·8034	7	4·5355
	8	12·3467	8	5·1834
	9	13·8900	9	5·8313
	10	15·4333	10	6·4792
	11	16·9766	11	7·1271

In Tirhoot and Monghyr the chief prevailing beegahs are of 4225 square yards and 3600 square yards, and the latter is also common in Sarun.

	Prevalent in parts of Tirhoot and Monghyr.					*Prevalent in Sarun, Tirhoot and Monghyr.*			
	Acres.	Beegahs.	Beegahs.	Acres.		Acres.	Beegahs.	Beegahs.	Acres.
4225 Square Yards.	1	1·1455	1	0·8729	3600 Square Yards.	1	1·3444	1	0·7438
	2	2·2910	2	1·7458		2	2·6888	2	1·4876
	3	3·4365	3	2·6187		3	4·0332	3	2·2314
	4	4·5820	4	3·4916		4	5·3776	4	2·9752
	5	5·7275	5	4·3645		5	6·7220	5	3·7190
	6	6·8730	6	5·2374		6	8·0664	6	4·4628
	7	8·0185	7	6·1103		7	9·4108	7	5·2066
	8	9·1640	8	6·9832		8	10·7552	8	5·9504
	9	10·3095	9	7·8561		9	12·0996	9	6·6942
	10	11·4550	10	8·7290		10	13·4440	10	7·4380
	11	12·6005	11	9·5019		11	14·7884	11	8·1818

In the Eastern part of Bengal the local measure is considerably larger, and assumes a variety of denominations. In Arracan, Chittagong, Tipperah, Bulloah, Backergunge and part of Mymensing, the *Droon* varies from 5 up to 195 acres. In Dacca, Furreedpore, Jessore, Pubna and Rajeshye, the *Khada* is the prevailing measure, running from 4 to 21 acres. In Assam and part of Mymensing, the *Poorah* ranges from $1\frac{1}{4}$ in the former to 25 acres in the latter district. In Sylhet, Jynteah and Cachar, the *Koolbah* is the known measure differing between 3 and 5 acres. The Cachar koolbah equals 23313·89 square yards, that in Jynteah 23633 square yards, and for Sylhet the following Table is given, the length of the measuring *null* or rod being 21 feet $8\frac{1}{8}$ inches, and the koolbah sides 28 and 12 of such nulls :

	The Sylhet Koolbah.			
	Acres.	Koolbahs	Koolbahs.	Acres.
17542·78 Square Yards.	1	0.2759	1	3·6245
	2	0·5518	2	7·2490
	3	0·8277	3	10·8735
	4	1·1036	4	14·4980
	5	1·3795	5	18·1225
	6	1·6554	6	21·7470
	7	1·9313	7	25·3715
	8	2·2072	8	28·9960
	9	2·4831	9	32·6205
	10	2·7590	10	36·2450
	11	3·0349	11	39·8695

For the ready conversion of beegahs of *any* number of square yards whatever, into corresponding acres, the following Table will be found useful:

Table for finding a Multiplier to convert Beegahs, or any other local measurement, of any *number of Square Yards, into corresponding Acres.*

Square Yards.	Multiplier.	Square Yards.	Multiplier.	Square Yards.	Multiplier.	Square Yards.	Multiplier.	Square Yards.	Multiplier.
48·40	·01	1016·40	·21	1984·40	·41	2952·40	·61	3920·40	·81
96·80	·02	1064·80	·22	2032·80	·42	3000·80	·62	3968·80	·82
145·20	·03	1113·20	·23	2081·20	·43	3049·20	·63	4017·20	·83
193·60	·04	1161·60	·24	2129·60	·44	3097·60	·64	4065·60	·84
242·00	·05	1210·00	·25	2178·00	·45	3146·00	·65	4114·00	·85
290·40	·06	1258·40	·26	2226·40	·46	3194·40	·66	4162·40	·86
338·80	·07	1306·80	·27	2274·80	·47	3242·80	·67	4210·80	·87
387·20	·08	1355·20	·28	2323·20	·48	3291·20	·68	4259·20	·88
435·60	·09	1403·60	·29	2371·60	·49	3339·60	·69	4307·60	·89
484·00	·10	1452·00	·30	2420·00	·50	3388·00	·70	4356·00	·90
532·40	·11	1500·40	·31	2468·40	·51	3436·40	·71	4404·40	·91
580·80	·12	1548·80	·32	2516·80	·52	3484·80	·72	4452·80	·92
629·20	·13	1597·20	·33	2565·20	·53	3533·20	·73	4501·20	·93
677·60	·14	1645·60	·34	2613·60	·54	3581·60	·74	4549·60	·94
726·00	·15	1694·00	·35	2662·00	·55	3630·00	·75	4598·00	·95
774·40	·16	1742·40	·36	2710·40	·56	3678·40	·76	4646·40	·96
822·80	·17	1790·80	·37	2758·80	·57	3726·80	·77	4694·80	·97
871·20	·18	1839·20	·38	2807·20	·58	3775·20	·78	4743·20	·98
919·60	·19	1887·60	·39	2855·60	·59	3823·60	·79	4791·60	·99
968·00	·20	1936·00	·40	2904·00	·60	3872·00	·80	4840·00	·100

RULE.—Take out from the column containing the Square Yards the nearest number to those contained in the Beegah, opposite which will be found its Multiplier, the difference wanting to complete the number of Square Yards in the Beegah, will then be taken out with its Multiplier and added to the former, and so on, until the actual number of Square Yards contained in the Beegah are extracted. The sum of these will give the Multiplier required.

NOTE.—In taking out any number of Square Yards less than 48·40, it is only necessary to remove the decimal point as many places to the left hand in the column of Square Yards as the number may be required, removing the points also as many places in the column of Multiplier.

EXAMPLE.

Required the Decimal Multiplier for a Beegah containing 1,600 square yards.

Square Yards..	1600	
Next nearest in Table	1597·20	·33
	2·80	·00058
	Sum	·33058

Therefore the beegah of 1,600 square yards equals ·33058 of an acre.

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Bengal Standard Beegah.

The multiplicity of the local measures in the Lower Provinces, and the excessive confusion and inconvenience felt thereby, has at last however produced its own cure. When an evil is at its zenith, there is some hope of amendment; by a Circular Order of the Sudder Board of Revenue, dated the 23rd November, 1849, the whole system has been broken down, and one uniform value given to the beegah for all the districts subject to the Board's jurisdiction, and to be used in all measurements carried on for the future, under their superintendence. The standard adopted is that of the puckha Calcutta beegah, of 14,400 square feet, or 1,600 square yards. The acre therefore is equivalent to 3·025 of such beegahs. It is not apparent on what principle or investigation this beegah has been assumed, differing so greatly as it does with all the local measures in Bengal Proper, as before shown; and it is to be regretted that whilst so great an innovation was in contemplation, either the British acre of 4,840 square yards was not at once introduced, as was the case in Orissa, or a beegah bearing some simple ratio to it, as has been done in the Delhi and other districts of the North-Western Provinces. The standard *Ilahy* guz of 33 inches being now more widely established in British India than any other local measure of length, everything possible should be done to extirpate the use of other measures not easily comparable with it; and all local land measures should be founded on some simple multiple of this standard, such as the Gunter's chain, which is the basis of the acre: no round number of yards can be introduced into such a system without retaining the inconvenient number 11 as a multiplier or divisor.

The *yard* therefore ought to be wholly discarded from our Indian system of measures, and everything referred to the Ilahy guz of 33 inches, or some multiple or submultiple of it, such as a *hath* of 16½ inches. Any beegah founded on either of these measures may be readily compared with the Gunter's chain of 66 feet, and through it with the English acre. It would have been preferable to this to have established the Bengal beegah, so that one acre might be equivalent to 3 beegahs, rather than 3·025 beegahs, although a *square* beegah of this value cannot be obtained. The *hath* of 16½ inches, which may be the basis of this beegah, and of its subdivisions the *cottah* and *chittack*, is *half* the Ilahy guz; and the two beegahs of Delhi and Bengal would be so easily comparable with each other, as to facilitate the process of adopting hereafter some land measure that would include both, if that should be thought desirable. But it is of far less importance that the *land* measures of two distant countries should be identical, than the measures *of length* should be so. An

uniform standard, whatever its size, is however of the greatest possible advantage and utility, and cannot be too highly appreciated.

The new beegah side is exactly 120 feet, or 80 haths, which squared, gives 14,400 feet or 1,600 square yards. The following will therefore be the relative values of the beegah and acre respectively.

1600 Square Yards.

The Bengal Standard Beegah.

Acres.	Beegahs.	Beegahs.	Acres.
1	3·025	1	0·33058
2	6·050	2	0·66116
3	9·075	3	0·99174
4	12·100	4	1·32232
5	15·125	5	1·65290
6	18·150	6	1·98348
7	21·175	7	2·31406
8	24·200	8	2·64464
9	27·225	9	2·97522
10	30·250	10	3·30580
11	33·275	11	3·63638

Of the lower denominations, 20 cottahs make one beegah, and 16 chittacks make one cottah; additional Tables for the conversion of roods and perches into cottahs and chittacks will be found in the Appendix, being too bulky for this place.

Khusrah and Thakbust Scale.

To adapt a convenient scale for this beegah, which shall be proportional with the one used for the Professional Survey, take the following:

Professional scale of 4 inches = 1 mile = 80 Gunter's chains; and 1 inch, or 20 chains = 1,320 feet.

Then 1 russee = 80 haths = 120 feet
and 11 „ = 1320 „

therefore 11 russees are equivalent to 1 inch, or 20 Gunter's chains on the same scale, and by increasing the scale four times 11 russees = 4 inches. By dividing 4 inches therefore into 11 equal parts, each will be equal to a russee or beegah side of 120 feet, and the quarter of such division or 30 feet will represent the chains actually employed, *two* of which squared, or 60 feet × 60 feet equal 3600 feet, or 5 cottahs. This scale will therefore be 330 feet or 2¾ beegahs to the inch, or 16 inches to the mile. The Khusrah measurements preformed with such chains, and protracted on such a scale, will bear precisely the ratio of 4 to 1 to the Professional Maps.

CHAPTER XXIII.

ON THE ORTHOGRAPHY OF NATIVE NAMES.

ONE of the most difficult subjects with which Europeans in this country have to deal, is the intelligible conversion of the vernacular into the English character, and it will be readily admitted, that Surveyors of all persons must be the most interested and concerned in following such a good system, that any person knowing the original and the substituted character, should be able to convert the one into the other without difficulty, and that the names of places so romanized on the geographical maps of the country should be at once recognizable and familiar to the ear. In a work like this, it may be expected that some fixed rules should be laid down for the guidance of the department, but any fixed system, is easier to propose than to find followers for. As regards spelling, some people are quite incorrigible, we shall endeavour however to place on record the prevailing methods heretofore existing in the great Trigonometrical as well as Revenue Surveys, together with such remarks on other systems as appear to be called for.

Sir Wm. Jones's method is at once elegant and phonical, and has found complete acceptance with learned and scientific men; it is therefore, with some slight modification, in use in the Great Trigonometrical and Topographical Surveys of India. The rules followed in these departments are very simple, and may be thus stated:

Rules for the orthography of native names.

1st. All vowels have the Italian sound, as in Sir Wm. Jones's rule; no others to be used.

2nd. The semi-vowels to be used only as consonants, such as *Y* in Yaholi.

3rd. All consonants have their ordinary sound, but express the harsh sound of *C* by *K* and the soft sound by *S*, whereby *C*, as an independent letter, becomes expunged.

4th. Express the soft sound of *G* universally by *J*, reserving the former of these letters in all cases to denote the harsh sound only.

5th. Dispense with the reduplication of consonants, as much as possible, because long words are an evil on maps.

6th. Drop superfluous letters of all kinds wherever they are so weak as to make it a matter of doubt whether they ought to be pronounced or not. Example *Hydrabad, Sikandrabad,* &c., wherein some persons introduce a short vowel between the *d* and *r*, and others do not.

7th. The old established orthography of historical names should not be interfered with, as they have become settled and familiar by long use, and it would be pedantic and presumptuous to alter them, and the same idea would not be conveyed. Thus write Meerut not *Mirat,* Hydrabad not *Haiderabad,* or *Huederabad* (according to Gilchrist), Beder not *Bidar,* Calcutta not *Kalkata,* Captain not *Kaptan,* Cawnpoor not *Kánpúr,* Allahabad, &c.

8th. Double consonants should never be used when single ones will answer, thus *Ph* instead of *F* is not advisable, as in Filaor not *Phillore,* neither *Ch* instead of *K,* although there is Italian authority for the latter.

This method is doubtless a phonical one, well adapted for general use, and scientific men will not agree to any deviation from Sir Wm. Jones; but, however learned Surveyors may be, the persons into whose hands their maps fall, may be very ignorant Englishmen, and it is extremely doubtful whether such a mode of pronunciation is intelligible to people of ordinary capacity and common-sense ideas.

The difference between the Foreign and English sound of the vowels *u* and *i*, is most likely to lead to confusion with strangers, and to prevent all possible mistakes the *oo* should stand for the Italian *u*, and *ee* for the Italian *i*, retaining the latter for diphthongs only—such a compromise would certainly enable the generality of people to pronounce better.*

* In addition to this, there is Dr. Duff's modification of Jones's system as now established and finally approved of by the Committee of the Calcutta Bible Society as laid down in a pamphlet on the "Progress and Present State of the Romanizing System." After a most careful investigation, the following romanized Urdu Alphabet was agreed upon and introduced with these remarks.

"The Committee of the Bible Society having thus furnished the most decisive proof of its earnest desire to consult the wishes and yield the utmost possible deference to the conscientious opinions of individual Missionaries throughout the country, it is fondly to be hoped that the *standard* of romanizing now fixed by the majority will be gladly hailed, embraced, and practically exemplified by all. It is fondly to be hoped that for the sake of that *general uniformity* which is so truly desirable and so absolutely indispensable to *full* success, every one will be cheerfully disposed to sacrifice any little *partiality* or *peculiarity* of opinion, which may be the offspring of isolated or individual minds."

The Hindustani Alphabet in the Roman Character.

A	B	Bh	P	Ph	T	Th	Ṭ	Ṭh	S	J	Jh	Ch	Chh	H			
a	b	bh	p	ph	t	th	ṭ	ṭh	s	j	jh	ch	chh	h			
ا	ب	بھ	پ	پھ	ت	تھ	ٹ	ٹھ	ث	ج	جھ	چ	چھ	ح			
Ḳh	D	Dh	Ḍ.	Ḍh	Z	R	Ṛ	Ṛh	Z	Zh	S	Sh	S	Z	T	Z	Ạ
ḳh	d	dh	ḍ	ḍh	z	r	ṛ	ṛh	z	zh	s	sh	s	z	t	z	ạ
خ	د	دھ	ڈ	ڈھ	ذ	ر	ڑ	ڑھ	ز	ژ	س	ش	ص	ض	ط	ظ	ع
G	F	Q	K	Kh	G	Gh	L	M	N	N	V	W	H	Y			
g	f	q	k	kh	g	gh	l	m	n	ṉ	v	w	h	y			
غ	ف	ق	ک	کھ	گ	گھ	ل	م	ن	ں	و	و	ه	ي			

Vowels.

a, á, i, í, u, ú, e, ai, o, au

ا آ اِ اِي اُ او ي يَ و وَ

ع *short*, a, i, u; *long* á í, ú

غ g or ġ.

In the Revenue Survey Department, Gilchrist's method has generally been employed, although no definite rules appear to have been laid down on this important subject. Like any other system whatever, if rigidly carried out, it is intelligible enough to those who have learned and practised it, but it has never found acceptance with the learned or scientific. It looks ugly, and adopts all the bad pronunciation of English. No other nation, but the English, ever give *u* the short sound of *but*. This is a fundamental assumption of Gilchrist's, and ruins the whole of his system, the chief merit of which is, the undeviating tenacity with which he adheres to it under all difficulties.

In the directions for Settlement Officers, promulgated under the authority of the Honourable Mr. Thomason, Lieutenant-Governor, North-Western Provinces, there is another alphabet proposed to be used in the conversion of names from the languages of the country into English. Transposing from one language to another by this method is easy, and it is particularly well adapted for the services, and having gained some footing, and being recognised by all the Settlement and other Revenue Officers, the Surveyors who have to follow their steps, and depend on their inquiries, are obliged in a great measure to resort to the same phraseology, and hence the more

scientific, but more difficult system of Jones, has never been followed by this branch of the Survey of India.

The following is the alphabet exemplified:

Alphabet proposed to be used in the conversion of names from the languages of the Country into English.

1	A.	*a.*	Atmanugur	आ	ا
			Ahunpoor		
			ᵖAhunpoor.		
2	B.	*b.*	Bareepoor	ब	ب
3	BH.	*b.h,*	Bhooaneepoor	भ	بهه
4	CH. CHH.	*ch, ch,h.*	Chichura	च, छ	چهه, چ
			Chhipagurh		
5	D.	*d.*	Dâk Bazar	ड, द	ڈ د
			Datanugur		
6	DH.	*dh.*	Dhurumpoor	ध, ढ	دهه
7	E.	*e,*	Ekeesghur	ए	
8	EE.	*e.e.*	Eeshwurnugur	ई	ایی
			Eesalpoor Edgurh		
9	F.	*f.*	Fureedpoor	फ	ف
10	G.	*g.*	Gunga Sagur	ग	گ
11	G,H. GH.	*g,h. gh.*	Ghur Mookhtesur	घ	گهه غ
			Ghazeepoor		
12	H.	*h.*	Huveleeshuhur	ह	ح هه ه
			Hat,h gaon		
			Hurjinspoor		
13	I.	*i.*	Iradutgunge	इ, ि	اِع
			Indurgurh		
			ᵖIlum bazar		
14	J.	*j.*	Jynugur, Jahilgurh	ज	ج
15	JH.	*j,h*	Jheel, Jharundeh	झ	جهه
16	K	*k.*	Kunkerpoor	क	ک
			Kake Deh		
17	K,H. KH	*k,h. kh.*	K,hurukpoor	ख	خ
			Khalisnugur		
18	L.	*l.*	Lalgurh	ल	ل
19	M.	*m.*	Mahinutabad	म	م
20	N.	*n.*	Nurayunpoor	न, ङ, ञ, ण	ن

21	O.	*o.*	Omedgaon	ओ ो	أ أ ر
			Olanuggur		
22	OO.	*o.o.*	Oondes	उ ऊ	ا او
			Oostadpoor		
23	OU.	*o.u.*	Oushandeh	औ	آر
24	P.	*p.*	Peepulgaon	प	پ
25	P,H.	*p,h.*	Phoolnugur	फ	پھ
26	Q.	*q.*	Qasimgunj		ق
27	R.R,H.	*r.r,h*	Rungpoor	र, ड़, ढ़	ر
			Rhotas		
28	S.	*s.*	Sareeram	स	س
			Sa ʼ dutgunj	ष श	ش
29	SH.	*s.h.*	Sholapoor]		
			Shureef bazar		
30	T.	*t,*	Tunk hadah	त	ت ٹ ط
31	T,H.	*t,h.*	Thanagurh	थ	تھ
32	U.	*u.*	Umretpoor	अ	آ ع
			ʼ Uleepoor, Ullahabad		
33	V.W.	*v.w.*	Wustabad	व,	و
			Vizeerpoor		
34	Y.	*y.*	Yarpoo, Yuabzar	य	اي عي
			Yy ʼ shnugur		
35	Z,ZH.	*z,zh.*	Zeeafutabad		ز ذ ض ظ ژ
			Zalimpoor, &c.		

The English alphabet having no letter capable of representing the ع Ain of the Persian, the use of this as contra-distinguished from A. E. I. O. or U. may be indicated by a mark-thus ʼ before or over the letter.*

This subject has been very much before the public in India of late years, and the action of the Government of India taken on it will be best understood from the Resolution of the Department of Revenue, Agriculture, and Commerce, dated the 20th August 1873, as follows :—

RESOLUTION.—The system of transliteration in the Roman character of Indian proper names, which had formed, since 1868, the subject of much discussion, was prescribed for adoption by the Government of India last year, and those orders were finally approved and confirmed by Her Majesty's Government.

2. The time has therefore passed for further discussion of the merits of alternative systems, and the system prescribed for adoption should be adhered to and carried into effect.

* The question of representing Oriental letters is also discussed in the Introduction to Wilson's "Glossary of Judicial and Revenue Terms," &c.

3. While, however, Her Majesty's Government have desired that the system shall be applied in the case of all the less known Indian names, they have also directed that the orthography of names of well-known places should be retained. His Excellency in Council also desires to give considerable latitude to Local Governments in respect to the extent to which the change should be immediately introduced.

4. His Excellency in Council trusts that the lists called for in the Circular from this Department, No. 15—400-415, dated the 17th October 1872, will now be carefully prepared in accordance with the principles laid down by the Government of India, and that they will be submitted with as little delay as possible. These lists will, after revision, be published for general information, and the orthography of all names included in them should, after such publication, be scrupulously adhered to in all official documents throughout India, with the exception of British Burmah. The rules which have been laid down for the transliteration of native names do not apply to the language of that province, and it accordingly is excepted from the present orders.

5. The opinion expressed by His Honor Sir William Muir in favor of a different system of spelling will, together with the other papers upon the subject, be forwarded for the information of the Secretary of State for India in Council.

6. The revision of the spelling of names of cantonments and military stations will be made in communication with the Military Department.

(Sd.) A. O. HUME,
Secretary to Government of India.

RULES FOR TRANSLITERATION.

Every Letter in the Vernacular must be uniformly represented by a certain letter in the Roman Character as follows:—

VOWELS.

Persian.		Devanagari.		Roman.	Pronunciation.
Initial.	Non-initial.	Initial.	Non-initial.		
ا	(zabar)	अ	not expressed	a	As in woman.
آ	ا	आ	ा	á	„ father.
اِ	(zer)	इ	ि	i	„ bit.
اِيـ	يـ or ي	ई	ी	í	„ machine.
اُ	ُ (pesh)	उ		u	„ pull.
اُو	وُ	ऊ	ू	ú	„ rude.
ايـ	يـ or ي	ए	े	e	„ grey.
اَيـ	يَـ or يَ	ऐ	ै	ai	„ aisle.
او	و	ओ	ो	o	„ hole.
اَو	وَ	औ	ौ	au	As *ou* in house (nearly), being a combination of the a and u above.

CONSONANTS.

PERSIAN.	DEVANAGARI.	ROMAN.
ب	ब	b
بھ	भ	bh
چ	च	ch
چھ	छ	chh
د or ڈ	द or ड	d
دھ or ڈھ	ध or ढ	dh
ف	wanting	f
گ	ग	g
گھ or غ	घ	gh
ج	ज	j
جھ	झ	jh
ک or ق	क	k
کھ or خ	ख	kh
—	क्ष	ksh
ل	ल	l
م	म	m
ن	न, ञ, ङ, ण, or anuswara	n
پ	प	p
پھ	फ	ph
ر or ڑ	र or ड़	r
ڑھ	ढ़	rh
ث , س or ص	स	s
ش	श or ष	sh
ت , ٹ or ط	त or ट	t
تھ or ٹھ	थ or ठ	th
و	व	w or v

Persian.	Devanagari.	Roman.
ي	य	y
ذ, ز, ض or ظ	wanting	z
ژ	ditto	zh
ع	ditto	omitted, the accompanying vowel only being expressed.
—	ज्ञ	gy

In addition to the above, the "Rules for the spelling of Indian Proper Names by W. W. Hunter, Esq., LL.D., Director-General of Statistics to the Government of India, published in 1871, are given in the Appendix.

Unfortunately, owing to divergence of opinions between the several Local Governments and the terms of the Resolution above given, the practical working out of the entire scheme has been greatly retarded, and uniformity of procedure or of acceptance is still a thing to be desired.

From J. Geoghegan, Esq., Officiating Secretary to the Government of India, Department of Agriculture, Revenue, and Commerce, to all Local Governments and Administrations,—

Nos. $\frac{}{92 \text{ to } 101}$, dated Fort William, the 28th February 1872.

I am directed to forward copies of a "Guide to the Orthography of Indian Proper Names," with a list of towns and villages in India, prepared by the Director-General of Statistics to the Government of India.

2. The general principles on which this compilation is based have already received the assent of the Government of India, and been acted upon by the Government of the Panjáb (as will be seen from the orders of that Government published at pages 178 to 187 of the *Panjáb Gazette*, dated 15th instant, copy of which is forwarded herewith).

3. It is rather as an illustration of the practical working out of sanctioned principles, than as an arbitrary declaration of the official spelling of certain names, that the Acting Governor-General in Council would invite . . . . to accept this list and adopt it as a guide. For it is far from being the wish of His Excellency in Council to stereotype the errors of detail necessarily incidental to the first uniform application of a new system to a variety of languages, or to shut the door against future improvement in a field in which improvement is to be expected and desired. On the other hand, it is desirable to popularise such principles as have already been accepted, and to secure and facilitate, as far as may be possible, a harmony of system in the official publications which most influence public usage.

4. Above all, in the work now going on in connection with the Gazetteer, uniformity is essential, and I am to request that all officers engaged in the work may be instructed to conform carefully to the plan of transliteration exemplified in Mr. Hunter's list.

CHAPTER XXIV.

General Statistics. Geographical, Revenue, and Agricultural Reports.

On Statistics.

The importance of statistical information is now universally felt and acknowledged, and the Revenue Survey Department, as might be expected, from the peculiar facilities at its disposal for the attainment of such information, during the progress of Survey operations in every remote part and corner of the country, is not behind-hand in rendering good and valuable service to this branch of scientific enquiry. The attention of Revenue Surveyors is particularly and urgently directed to this point by the Circular Orders of the department, and the Annual Returns are not deemed complete without a full and succinct account, geographical and statistical, of every pergunnah of the district under survey. The Court of Directors, in their despatch, No. 6 of 1846, dated the 3rd June, which has been printed and circulated for general guidance, lay particular stress on the great practical importance of this duty, and on the advantage which may be expected from the transmission home of such information as to local details, which *so many of their servants* cannot fail to possess. The heads of information, most desirable to be collected, are likewise detailed in this despatch, which includes also full and particular instructions as to the mode of collecting the same, and enjoins the most rigid accuracy as to matters of fact, without which all statistics would be worse than useless, tending only to mislead.*

In the directions for Settlement Officers, North-Western Provinces, para. 41, it is specially noted that the Surveyors are to give returns of population, wells, and ploughs, and the mode of recording this and other useful information for every village coming under survey, is shewn in the register, Plate XI. This, together with descriptive remarks as to the state of prosperity, trade, distribution of the land, &c., furnishes the ground-work for the pergunnah statement and the general district report.

* For some valuable information, useful alike to the Surveyor or Settlement Officer, *vide* a Paper in Volume No. 164, Journal of the Asiatic Society of Bengal, by James Alexander, Esq., B.C.S., "On the Tenures and Fiscal Relations of the Owners and Occupants of the Soil in Bengal, Behar, and Orissa."

In unsettled provinces, where an assessment follows the survey, and a Khusrah measurement is universal, the statistical enquiries are pursued by the Ameen and recorded in the vernacular with his Khusrah Field-book, and from the length of time every village must be occupied by this Officer for the purpose of prosecuting the measurement, the time and means at his disposal are very considerable for eliciting the required details. These, however, are checked again by the Purtall Ameen, and by the Supervising Officer in comparison with lists (*Khaneh Shumareh*) demanded and obtained from the village authorities, and the investigations of Putwarries and others. The Settlement Officer again has numerous opportunities for testing these returns at the time of assessment. It may, therefore, be inferred that the information thus gleaned is as worthy of confidence as could be expected, and no difficulty whatever exists in procuring it, if rightly and fairly sought for on the part of the Ameens. The character, however, of these men, and the cloak made of the power in their hands to extort money from the people, should induce great caution in receiving their statements, or of entrusting any additional powers in their hands beyond what is absolutely essential.

In the Bengal and Behar Provinces, where the Khusrah measurement is only partial, and not more than from 15 to 20 per cent. of the villages are visited by the Ameens, the mode of prosecuting statistical enquiries must be through other agency. The demarcation establishments are here brought into use for this purpose, and the assistants, employed in the interior professional detail survey, may be made available; and whatever difficulties arise, they can alone be overcome by the intelligence, activity, and ability of the Officer in charge of the survey.

The following comprise the heads of information, all or a portion of which may be reported on with advantage; and annexed is a tabular statement extracted from an actual report made by the late talented officer whose name it bears, and which may be copied with safety.

LAND.—Geographical position, Extent.
Boundaries, Divisions, Subdivisions.
Climate, Aspect, Superficial configuration, Mountains, Hills.
Geological structure, Mines, and Minerals.*
Forests, jungle, &c. Plains, soil and productions, modes of cultivation.
Prices of principal products.
Tenure and occupation, modes and rates of assessment.
Labor employed and its remuneration.

* *Vide* Appendix, "Desiderata for the Museum of Economic Geology of India."

WATER.—Navigable rivers.
Description and length of.
How far navigable.
Origin and source.
Banks and soil of bed.
Vessels employed on them.
Shoals, velocity.
LAKES.—Description and situation.
Height above the sea.
CANALS.—Their purposes.
Length and depth.
Vessels employed on them.
Cost and return on the outlay.
Wells, puckha and kutcha, tanks, &c.
Means of irrigation.
CITIES.—Towns and villages.
Situation and general description.
Number of houses and whether puckha or kutcha.
General caste of inhabitants.
Remarkable buildings, Temples, Shewallahs, Mundérs, Durgahs or Mosques.
Public establishments.
Thannahs, Tuhseeldarees, Moonsiffees.
Police Custom and Salt Chowkees.
Schools, Churches.
POPULATION.—Census of people of different caste.
Agricultural and Non-Agricultural, Average number per Square Mile.
Employment.
Condition and Physical constitution.
Health and disease.
WEALTH.—Education and method of pursuing it.
Charitable institutions not educational.
State of litigation and of crimes.
Police, number, remuneration and efficiency.
COMMERCE.—Manufactures.
Capital employed.
Weights and Measures, Coins.
Modes of transit and communication.
By land, high and metalled roads, passes and defiles, kutcha cart roads, footpaths.
By water.
Impediments and their duration.
Fords, ferries, and bridges.
Fisheries.
Postal arrangements.
Taxation.
Sources of revenue and produce of each tax.
Mode of collection.

COMMERCE.—Fairs and markets.

History and antiquity, facts illustrative of early or more recent history, and changes, political or agricultural.

Factories, indigo, sugar, saltpetre, silk.

Golahs, Salt.

Agricultural implements.

AGRICULTURAL INDUSTRY.—Ploughs, domestic animals.

Cattle, draft and grazing.

Buffaloes, &c.

Wild sports.

Wild animals.

In the Memoir on the Statistics of the North-Western Provinces, compiled under the order of the Honourable the Lieutenant-Governor, and published in 1848, it is stated that the late settlement of those provinces has provided many statistical facts which it has been the aim of that Government to bring together and place on record with precision, and that in order to create greater confidence in the correctness of the revised statistical return, the Memoir was compiled, so as to place permanently on record the mode in which the information was collected, and the authority on which each of the facts rests. In this work much valuable instruction is afforded, and we have extracted some of the leading rules for a fair enumeration of the people, or of houses.* The statistical

* Para. 14. "In such census it will only be necessary to separate the people into the classes mentioned in the Table. Separation into males and females, of boys and girls, is useless, because these classes will not be accurately reported, nor will the distinctions be uniformly observed."

15. "All persons who derive their subsistence, in whole or in part, from the land, whether in the form of wages or rent, should be shown as cultivators, even though they may have other sources of income."

16. "Any census based on actual enumeration of the people will probably be vexatious and erroneous. It will be better to rest the calculation on the number of houses or families."

17. "A house or family must be defined according to its local signification; perhaps it may generally be defined as a family living together, inhabiting a distinct part of a tenement, or the whole of one or more tenements in the same enclosure."

18. "The number of houses or families being thus ascertained, the number of persons actually resident in a certain number of such houses may be counted, and the average may be applied to the whole. The value of the result will depend upon the care and the discrimination with which this is done."

19. "The enumeration should take place in those houses or villages where the object of the process is most likely to be understood, and where the co-operation of the zemindars and other influential inhabitants can be secured."

20. "Distinct averages should be assumed for different classes of the inhabitants. Thus the average in cities or towns may be different from what it is in villages, the average in puckha houses from that in cutcha houses, the average in one pergunnah, from that in another; in Mahomedan families from that in Hindoo families; or Brahmin or Rajpoot families, from that in Chumar or Passee families."

return of the six divisions, comprising 32 districts, gives 322 as the average number of persons to the British statute mile, and 1·99 as the number of acres to each person. This is a high average population, and it has consequently been received with some doubt and suspicion, from the comparative statements of other countries. China, universally considered one of the most densely populated countries, is only 277 to the square mile, according to "Davis's China" census of 1812, and the only European country approaching to this Indian average is Belgium, which is 392, on the geographical mile of 847 acres, equivalent to 296 on the statute mile of 640 acres, but as stated in the Memoir "there is good reason to suppose that the averages in the well-peopled parts of India are higher than in the most populous countries of Europe;" and so it would decidedly appear, not only from the results published in this Memoir, but from the subsequent researches made in Behar and Bengal, as the progress of the Revenue Survey advances, all of which tend to keep up a high estimate. The insertion here of the population of the North-Western districts may serve as a guide, we have therefore extracted such columns from the printed return. At the

21. "The returns when given in by the Tuhseeldars should be tested by the Collector. This is easily effected when the details are given Mouzahwar, for if the returns for a few Mouzahs taken indiscriminately are found to be correct, the whole may be assumed to be so."

22. "The following general rules may be found useful in judging of the accuracy of returns regarding population."

23. "The average number of persons to a house or family is between 4 and 5. From peculiar circumstances, in certain localities, it may fall below or rise above this standard."

24. "The average number of persons to a square geographical mile of 847·2 acres, in the chief countries in Europe, is given in the margin.* There is good reason to believe that the averages in the well-peopled parts of India are higher than in the most populous countries of Europe."

* Belgium	392
British Isles	220
France	208
Saxony	314
Wirtemberg	266
Tuscany	302
Sweden	22
Norway	11
Russia Proper	36
Europe	80

Taken from the Map of Europe—published by the Society for the Diffusion of Useful Knowledge.

25. "The number of adult females is found to be in excess of that of adult males, but the number of boys is much larger than of girls. The cause of this, in some measure is, that females are considered to have passed from girlhood at an earlier age than males from boyhood." *Vide* Memoir on Statistics, pages 8 and 9.

Para. 3. "The definition of a house or family, and the ground on which the number of souls to a house or family is stated, require to be very carefully examined, and the mode as well as the result of the examination to be fully stated."

4. "Care does not seem to be generally taken in discriminating between the agricultural and non-agricultural classes. On referring to para. 15 of the former printed Circular, you will observe *that the members of all families who derive their support or any part of their income from the cultivation of land are to be entered as agricultural, whether or not they actually hold the plough or personally conduct the usual agricultural operations.*" *Vide* Memoir of Statistics, page 14.

Agricultural, Revenue, *, Jubbalpoor, made up to the 1st of October, 1842,*

Designation of Tuhseeldaree.	NAMES OF TALOOKAS	Total.	STATISTICS. Population. Hindoos. Males.	Females.	Mahomedans. Males	Females.	Total months.	Pucka Edifices. Shewalahs.	Munders.	Gudhee.	Public Establishments. Tuhseeldaree.	Thannah.	Police Chowkies.	Custom ditto.	Ferries.	Distilleries	Fairs and Markets. Number of Fairs held in the year.	Number of Markets held in the Week.
Shahpoorah Khas.	Chowbeesa..	28	726	633	0	0	1359	..	..	..	..	..	..	..	..	1	..	1
	Kuthotcea	66	994	960	0	0	1954	..	..	..	..	..	..	..	..	..	..	..
	Mookutpoor	97	5346	4429	18	18	9811	2	..	1	..	1	..	..	..	31	..	4
	Muhudwanee	05	459	403	0	0	862	..	..	..	..	..	..	..	..	..	..	1
	Niwans	13	3016	2570	0	0	5586	2	..	..	..	..	..	..	..	5	..	1
	Pirtab Gurh	97	1866	1805	8	4	3683	31	9	..	..	..	..	..	..	2	..	1
	Sub-Talooka Lumneo ..																	
	Rameepoor Bijhowree ..	76	2300	1970	0	0	4270	2	..	..	..	..	..	..	..	6	..	1
	Shahpoorah	96	3791	3494	46	48	7382	2	4	..	1	1	..	..	..	18	..	2
	Shahpoor	31	3619	3227	8	5	6859	2	..	..	..	..	..	..	..	14	..	2
	Sub-Talooka Kushoy Sonda																	
	Grand Total	39	22120	19491	80	75	41766	41	13	1	1	2	..	..	..	77	..	13

Average per Square Mile .. Population.. .. .. 16·23

ABSTRACT.—The average 4 to 9 amongst the Hindoos; and 16 to 15 amongst the Mahomedans; on the whole Population, as 10 to 9

same time, the discrepancies between the averages of many of the districts in this statement are still so large as to leave considerable room for further doubt, Azimghur, Jounpore, and Ghazeepore being nearly *double* of Allahabad and several other districts and larger than Agra or Delhi. The general average, however, (322 per square mile) is *one-third* lower than that taken in 1826 (484 per square mile) and commented on in para. 17 of the Court's Despatch.

Revised Statistical Return of Area and Population in the Districts of the North-Western Provinces, prepared in 1848.

Divisions.	Districts.	Area in Square Miles of 640 acres each.	Population.					Number of Persons to each Square British Statute Mile of 640 Acres each.	Number of Acres to each Person.
			Hindoo.		Mahomedan and others not Hindoo.		Total.		
			Agricultural.	Non-Agricultural.	Agricultural.	Non-Agricultural.			
Delhie.	Panceput ..	1279 9	125593	60601	24781	72445	283120	221·4	2·88
	Hurreeanah ..	3300·8	154671	21346	37431	11632	225086	68 2	9·38
	Delhie ..	602·5	85418	129066	9227	82809	306550	508 8	1 25
	Rohtuck ..	1310 9	150572	81541	16720	45286	294119	219·3	2·92
	Goorgaon ..	1912·3	176328	105180	109792	69026	460326	237·0	2·70
Meerut.	Seharunpore ..	2165 4	273513	62971	139907	70932	547353	252·8	2·53
	Mozuffernuggur	1617·0	172304	218341	61145	85504	537591	331 8	1·93
	Meerut ..	2332·9	329133	327701	62076	140923	860736	368·9	1·73
	Boolundshuhur.	1855·1	309237	261614	44061	84481	699393	377 0	1 69
	Allygurh ..	2149·2	315642	336150	21880	65684	739356	341·0	1·86
Rohilcund.	Bijnour ..	1904 0	225049	190515	44343	160639	620546	325·9	1·96
	Moradabad ..	2967·3	438387	222084	170 21	166867	997362	336 0	1 90
	Budaon ..	2368·4	557797	154270	57314	56301	825712	318 7	1·83
	Bareilly and Pillibheet.	2937·7	668074	215721	113594	146268	1143657	389·3	1 64
	Shahjehanpore .	2483·3	436166	124420	134520	117482	812588	327 3	1·95
Agra.	Muttra ..	1607·1	349065	299627	14066	38930	701688	436·6	1·46
	Agra ..	1860 8	466313	276350	17686	67871	828220	445·0	1·44
	Furruckabad ..	1909·8	514529	238895	31792	66583	851799	447·6	1·43
	Mynpoorie ..	2009·0	441002	158987	13700	26120	639809	318·5	2·01
	Etawah ..	1674·6	284838	170524	4691	21171	481221	287·3	2·23
Allahabad.	Cawnpore ..	2337·0	565249	353038	18211	56533	993031	424·9	1·51
	Futtehpore ..	1583·3	263191	197267	21776	28895	511132	322 8	1 98
	Humeerpore and Calpee.	2240·5	299558	120125	10223	22185	452091	201·8	3·17
	Banda ..	2878·8	375777	142309	16007	18433	552526	191·3	3·33
	Allahabad ..	2801·1	436839	177681	48273	47017	710263	253·6	2·52
Benares.	Goruckpore ..	7346·5	1779678	331247	198765	66843	2376533	323·5	1·97
	Azimghur ..	2520·3	915431	241602	70646	86271	1313950	521·3	1·23
	Jounpore ..	1552·2	563078	156753	30620	48052	798503	514·1	1·24
	Mirzapore ..	5244·8	425689	357058	11113	37528	831388	158·5	4·03
	Benares ..	994·5	356026	320024	5662	59714	741426	745 5	0·86
	Ghazeepore ..	2187·4	673743	271676	31518	82320	1059287	484·3	1·32
	Grand Total ..	71985·4	13127956	6324690	1596277	2150745	23199668	322·3	1·99

The following statement, showing the average rate of Population per square mile in the North-Western Provinces, has been obtained from the "Report on the Census" taken on the 1st January 1853, and computed from official documents by G. F. Christian, Esq. The result, it will be observed, gives a still higher average population per square mile than the Table of 1848, being in the proportion of 420 to 322 souls.

Division.	Districts.	Square Miles.	Mouzahs.	Houses.	Population.	Average rate of population per Square Mile.
Delhie	Paneeput	1,269·9	531	85,323	389,085	306
	Hissar	3,294·2	653	66,862	330,852	100
	Delhie	789·7	568	97,648	435,744	552
	Rohtuck	1,340·4	300	90,058	377,013	281
	Goorgaon	1,939·1	1,274	167,274	662,486	342
	Total	8,633·3	3,333	517,165	2,195,180	254
Meerut	Suharunpore	2,162·3	1,904	168,989	801,325	371
	Moozuffernuggur	1,616·3	1,138	142,505	672,861	402
	Meerut	2,200·1	1,638	233,928	1,135,072	515
	Booluushuhur	1,823 6	1,576	147,204	778,312	427
	Allygurh	2,153·1	1,997	226,619	1,134,565	527
	Total	9,985·7	8,253	919,245	4,522,165	453
Rohilcund	Bijnore	1,900·0	3,030	140,520	695,521	366
	Moradabad	2,698·8	3,484	233 581	1,138,461	422
	Budaon	2,401·9	2,232	231,381	1,019,161	424
	Bareilly	3,119·1	3,563	269,562	1,378,268	442
	Shahjehanpore	2,308·4	2,785	203,709	986,096	427
	Total	12,428·2	15,091	1,078,753	5,217,507	419
Agra	Muttra	1,613·4	1,019	192,757	862,909	535
	Agra	1,861·9	1,143	211,338	1,001,961	536
	Furruckabad	2,122 2	2,017	262,174	1,064,607	501
	Mynpoory	2,002 2	1,314	181,247	832,714	412
	Etawah	1,677·0	1,495	121,451	610,965	365
	Total	9,298·4	7,018	968,967	4,373,156	465
Allahabad	Cawnpore	2,348·0	2,257	275,140	1,174,556	500
	Futtehpoor	1,583·1	1,617	153.930	679,787	421
	Humeerpoor	2,211·6	997	125,357	548,604	245
	Bandah	3,009 6	1,257	170,102	743,872	247
	Allahabad	2,788·7	4,003	290,531	1,379,788	495
	Total	11,971·0	10,131	1,015,060	4,526,607	378
Benares	Goruckpoor	7,340 2	15,714	521,736	3,087,874	421
	Azimgurh	2,516·4	6,280	288,161	1,653,251	657
	Jounpoor	5,559·2	3,431	231,270	1,143,749	737
	Mirzapoor	1,152·3	5,280	222,398	1.104,315	214
	Benares	995·5	2,296	177,588	851,757	856
	Ghazeepoor	2,181·0	5,088	297,346	1,596,324	752
	Total	19,737·6	38,079	1,738,499	9,437,270	478
	Grand Total	72,054·2	81,908	6,237,689	30,271,885	420

Bengal and Behar Statistics.

In the first few districts which came under survey in these Provinces, Statistical enquiries were unfortunately omitted, and as no settlement follows the survey, the deficiency has not been made good; neither in those districts where the information has been collected can the results be so satisfactory and trustworthy as in the North-West Provinces, where double and treble investigations have been prosecuted. For the sake of completeness and comparison of the data given for different districts, it is to be hoped that the subject will not be lost sight of, but that it may be prosecuted in the same manner as described in the Memoir on the North-West Provinces. The following table exhibits all the details at present procurable for the Lower Provinces, distinguishing those districts, which have actually come under investigation by the Revenue Survey, taken either by an actual census in some districts, or by the enumeration of houses, and estimate of a certain number of souls per house, checked by another estimate drawn from the land under cultivation in some instances.* In several of the districts, however, the calculation is based only on partial areas, comprising certain Pergunnahs, yielding a certain average, and this number has been again assumed for the entire district. The average on the 14 districts so collected amounts to 246

* The only manner that I have of calculating the population is from the extent of cultivation, which is of course liable to great error. Two calculations may be founded on this basis.

First, it will appear in my account of the agriculture of this district, that about 480,000 ploughs are required, and one man is the usual allowance for each plough. The men employed in actual agriculture cannot therefore be less than 480,000, and these, I imagine, will be nearly one-fifth of their families including old people and children, which will make the agricultural population 2,400,000. Now considering the very imperfect state of agriculture, and the rudeness of the arts in this district, I do not think that we can add more than one-fourth of this number for all the other classes of society, especially as a quantity of grain is exported. This will give 3,000,000 for the total population, being about 558 persons for each square mile (on an area of 5,374 square miles).—Secondly, an estimate may be formed from the quantity of produce; and rice being the chief food of the people we may consider that alone. The total quantity of rough rice, after deducting seed, that I have calculated to be annually raised in this district, is about 36,800,000 muns, which, according to the trials that I made, will give 27,650,000 muns of clean rice. Now I have supposed, that to the value of 3,200,000 rupees of rice, or 4,400,050 muns are exported, and there will remain for consumption 23,250,000 muns Calcutta weight. Then, allowing half a seer of 96 sicca weight for each person daily, which is the calculation usually made in this district, this quantity of rice will feed more than 4,000,000 of people; considerable deductions however must be allowed for grain that is wasted, distilled, consumed by fire, eaten by cattle, and used in the arts; but still this population seems to be exaggerated, and the calculation founded on the number of ploughs seems more suitable to reality.—*Historical Description of Dinagepur District, by Buchanan (Hamilton), Book 2, page 67.*

per square mile, and the average deducible from the Population Returns, given in the *Agra Guide* and *Gazetteer* on nine other districts, is 189 per square mile, the general average on the entire area of 74,264 square miles being 219 per square mile, and which approximates closely with the estimate made in 1822, as noticed by the Court of Directors, *viz.*, 243 per square mile, on an area of about double of what is here given. This calculation, although roughly made, seems entitled to some confidence. It does not embrace the populous cities of Calcutta, Dacca or Moorsheda-bad, or the thickly-populated Districts of Hooghly, Kishnaghur, Baraset, &c., but until the whole country has been carefully and minutely explored, and much more labor and pains expended than have heretofore been devoted to this interesting and useful science, it will be in vain to expect absolute accuracy.

NOTE.—*The Census Returns and Administration Reports which are now available* (1874) *furnish much valuable information regarding the area and population of British India, and tables collated from these sources are given at the end of this Chapter, which it is hoped will be useful for purposes of general reference.*

Return of Population of the undermentioned Districts of Bengal and Behar, derived from the Records of the Revenue Survey, the Bengal Guide and Gazetteer, and other sources.

No.	Districts.	Area in Square Miles.	Return of Population derived from the Records of the Revenue Survey.			Approximate Return of Population derived from the Bengal Guide and Gazetteer, and other sources of Districts, which have not come under enquiry during the progress of the Revenue Survey.		Remarks.
			Number of houses.	Total Population.	Average number of Souls per Sq. Mile.	Total Population.	Average number of Souls per Sq. Mile.	
1	Pooree	2697	109916	524729	232	......	......	Census taken of population on the entire district.
2	Cuttack	3062	220688	553073	213	......	......	
3	Balasore	1876	96286	481432	257	......	......	On the average population of 31 Pergunnahs, by a census actually taken.
4	Midnapore	4018	202827	811308	202	......	......	On an examination of the houses in 13 Pergunnahs at 4 per house.
5	Hidglee	1014	38211	152844	151	......	......	Ditto ditto.
6	Chittagong	2717	103925	415701	153	......	......	On the average population of 3 Pergunnahs checked on the estimate of land under cultivation, assuming that 5 acres will support a family of 6 souls.
7	Sylhet (part of) ..	114	21134	24576	245	......	......	Census taken of population, and every house measured and recorded.
8	Jynteeah	459	36605	111355	255	......	......	
9	Cachar	650	32579	38121	102	......	......	
10	Patna	1828	127374	509496	278	......	......	On examination of houses, assuming 4 souls per house.
11	Tirhoot	6114	326609	1633045	267	......	......	Ditto ditto at 5 souls per house.
12	Purneeah	5742	490383	1961532	342	......	......	On examination of houses of 22 Pergunnahs at 4 per house.
13	24-Pergunnahs (part of)	1800	171000	684000	380	......	......	On ditto at 4 per house.
14	Maldah	1288	152552	281380	218	......	......	On ditto at 2½ per house.
15	Sarun	6394	......	......	....	973372	152	Assumed chiefly from the Chowkedarree Tax Papers, by Civil Authorities of Districts, as quoted in the Gazetteer for 1841.
16	Shahabad	4403	......	......	....	919904	209	
17	Behar	5694	......	......	....	1000000	176	
18	Rajshahye	2812	......	......	....	950000	338	
19	Rungpore	4563	......	......	....	121430	266	
20	Dacca	4726	......	......	....	1152215	244	
21	Mymensingh	7000	......	......	....	1624183	232	
22	Jessore	3363	......	......	....	903000	268	
23	Burdwan	2112	......	......	....	500000	237	
		54264	2130089	8182592	235·35	8144104	198·31	General Average 216·83 per Square Mile.

The following Return of Population of the Districts of Bengal and Behar, derived from the Records of the Revenue Survey, the Bengal Guide and Gazetteer and other sources, has been compiled up to the end of 1854, but the results of the Unsurveyed Districts cannot be in any way relied on, the areas of which, however, have been very carefully checked.

Districts.	Area in Square Miles.	Return of Population derived from the Records of the Revenue Survey			Approximate Return of Population derived from the Bengal Guide and Gazetteer, and other sources of Districts which have not come under enquiry during the progress of the Revenue Survey.		Remarks.
		Number of Houses.	Total Population.	Average number of Souls per Sq. Mile.	Total Population.	Average number of Souls per Sq. Mile	
Pooree	2697	109916	524729	232	......	......	Census taken of population on the entire district.
Cuttack	3062	220688	553073	213	.. ..	......	
Balasore	1876	96286	481432	257	......	......	On the average population of 31 Pergunnahs by a census actually taken.
Midnapore	4018	202827	811308	204	......	......	On an examination of the houses in 13 Pergunnahs at 4 per house.
Hidglee	1014	38211	152844	141	......	......	Ditto ditto.
Chittagong	2717	103925	415701	153	......	......	On the average population of 3 Pergunnahs checked on the estimate of land under cultivation, assuming that 5 acres will support a family of 6 souls.
Sylhet (part of) ..	114	21134	24576	245	......	....	Census taken of population.
Jynteeah	459	36605	111355	255	......	......	
Cachar	650	32579	38121	102	......	......	
Patna	1828	127374	509496	278	......	......	On examination of houses assuming 4 souls per house.
Tirhoot	6114	326609	1633045	267	......	......	Ditto ditto at 5 souls per house
Purneeah	5712	490383	1961532	344	....	......	On examination of houses of 22 Pergunnahs at 4 per house.
City of Calcutta ..	7¾	62565	361369	46628	......	......	Census of population taken independent of houses.
Dhee Punchanundgram..	23¼	23748	118740	5107	......	......	
24-Pergunnahs ..	1005	92566	461377	459	......	......	Excluding Dhee Punchanundgram and the city of Calcutta.

Baraset	1241	82693	485827	391	......	......	Census of population taken independent of houses.
Beerbhoom	3114	173861	514597	165½	......	......	On a careful investigation of houses, assuming 5 persons to each house.
Maldah	1288	62379	311895	242	......	......	
Bhaugulpore, north of the Ganges	1699	90460	452300	266	......	......	Assumed chiefly from the Chowkeedaree Tax Papers by Civil Authorities of Districts quoted in the Gazetteer.
Ditto, south of the Ganges	6102	......	......	....	1547700	256	
Rajshahye	2990	......	771528	258	......	......	Assumed chiefly from the Chowkeedaree Tax Papers, by Civil Authorities of Districts, quoted in the Gazetteer, and supposed to be very incorrect.
Hooghly	2007	......	......	....	1200000	598	
Sarun	6394	......	......	....	973372	152	
Shahabad	4403	......	......	....	919904	209	
Behar	5694	......	......	....	1000000	176	
Rungpore	3377	......	......	....	2559000	758	
Dacca	2024	......	......	....	1152215	266	
Dacca Julalpore ..	2304	......	......	....			
Mymensing	6864	......	......	....	1624183	236	
Jessore	3283	......	......	....	903000	275	
Burdwan	2268	......	......	....	500000	237	
Monghyr	3599	......	......	....	800000	222¼	Taken from the Official Return as given in the "Friend of India," dated 9th March 1854. Until the whole of the Districts in Bengal have been surveyed, it is impossible to arrive at even an approximation of the truth.
Bancoorah	1618	......	......	....	480000	296	
Moorshedabad ..	2723	......	......	....	1045000	384	
Dinagepore	3542	......	......	....	1200000	339	
Backergunge	3515	......	......	....	733800	208	
Tipperah	2280	......	......	....	1406950	338	
Bulloah	1875	......	......	....			
Bograh	1466	......	......	....	900000	614	
Nuddeah	3064	......	......	....	298736	97	
Pubnah	1958	......	......	....	600000	306	
Sylhet	4900	......	......	....	1083720	221	
Grand Total ..	116909	2394809	10694845	250	18490010	247	General Average 250.

BENGAL

UNDER THE JURISDICTION OF THE LIEUTENANT-GOVERNOR.

From Census Report of Bengal, 1872.

Division.	District.	Area in Square Miles.	Number of Villages, Mouzahs, or Townships.	Number of Houses.	Total Population—Male and Female.	No. of Souls per Square Mile.
	Western Districts.					
BURDWAN.	Burdwan ...	3,523	5,191	435,416	2,034,745	578
	Bancoorah ...	1,346	2,028	104,687	526,772	391
	Beerbhoom ...	1,344	2,471	159,940	695,921	518
	Midnapore ...	5,082	12,962	446,045	2,540,963	500
	Hooghly with Howrah ...	1,421	3,190	322,703	1,488,556	1,045
	Divisional Total ...	12,719	25,842	1,468,791	7,286,957	573
	Central Districts.					
PRESIDENCY.	24-Pergunnahs* ...	2,788	4,980	393,737	2,210,047	793
	Calcutta ...	8	1	38,864	447,601	55,950
	Total ...	2,796	4,981	432,601	2,657,648	950
	Nuddea ...	3,421	3,691	352,017	1,812,795	530
	Jessore ...	3,658	4,247	313,660	2,075,021	567
	Divisional Total ...	9,875	12,919	1,098,278	6,545,464	663
RAJSHAHYE.	Moorshedabad ...	2,578	3,753	303,561	1,353,626	525
	Dinagepore ...	4,126	7,108	264,526	1,501,924	364
	Malda ...	1,813	2,100	129,579	676,426	373
	Rajshahye ...	2,234	4,228	246,371	1,310,729	587
	Rungpore ...	3,476	4,206	331,079	2,149,972	619
	Bograh ...	1,501	2,666	127,099	689,467	459
	Pubna ...	1,966	2,792	198,220	1,211,594	616
	Divisional Total ...	17,694	26,853	1,600,435	8,893,738	503
COOCH BEHAR.	Darjeeling ...	1.234	...	18,864	94,712	77
	Julpigoree ...	2,906	...	69,648	418,665	144
	Cooch Behar ...	1,307	...	81,820	532,565	407
	Divisional Total ...	5,447	...	170,332	1,045,942	192
	Eastern Districts.					
DACCA.	Dacca ...	2,897	5,016	290,593	1,852,993	640
	Furreedpore ...	1,496	2,307	157,518	1,012,589	677
	Backergunge ...	4,935	4,269	321,657	2,377,433	482
	Mymensingh ...	6,293	7,601	308,008	2,349,917	373
	Divisional Total ...	15,621	19,193	1,077,776	7,592,932	486

* Not including Soonderbuns, of which the estimated area is 5,341 square miles—population unknown.

BENGAL.—(*Continued.*)

Division.	District.	Area in Square Miles.	Number of Villages, Mouzahs, or Townships.	Number of Houses.	Total Population—Male and Female.	Average Number of Souls per Square Mile.
	Eastern Districts.—(Contd.)					
CHITTAGONG.	Chittagong ...	2,498	1,062	197,104	1,127,402	451
	Noakholly ...	1,557	2,034	142,155	713,934	459
	Tipperah ...	2,655	6,150	307,011	1,533,931	578
	Chittagong Hill Tracts ...	6,882	...	13,354	69,607	10
	Hill Tipperah ...	3,867	...	6,329	35,262	9
	Divisional Total ...	17.459	...	665,953	3,480,136	199
	TOTAL FOR BENGAL ...	85,483	...	6,405,470	36,769,735	430
	BEHAR.					
PATNA.	Patna ...	2,101	3,412	269,814	1,559,638	742
	Gya ...	4,718	6,530	327,815	1,949,750	413
	Shahabad ...	4,385	5,110	275,041	1,723,974	393
	Tirhoot ...	6,343	7,337	642,087	4,384,706	691
	Sarun ...	2,654	4.350	293,524	2,063,860	778
	Champaran ...	3,531	2,299	242,228	1,440,815	408
	Divisional Total ...	23,732	29,038	2,050,539	13,122,743	553
BHAUGULPORE.	Monghyr ...	3,913	2,457	328,174	1,812,986	463
	Bhaugulpore ...	4,327	2,739	329,372	1,826,290	422
	Purneah ...	4,957	4,179	313.447	1,714,795	346
	Sonthal Pergunnahs ...	5,488	9,872	230,504	1,259,287	229
	Divisional Total ...	18,685	19,247	1,201,497	6,613,358	354
	TOTAL FOR BEHAR ...	42,417	48,285	3,252,036	19,736,101	465
	ORISSA.					
CUTTACK.	Cuttack ...	3,178	5,500	281,430	1,494,784	470
	Pooree ...	2,473	3,175	143,920	769,674	311
	Balasore ...	2,066	3,266	138,913	770,232	373
	Tributary Mehals ...	16,184	10,178	253,284	1,283,309	79
	TOTAL FOR ORISSA ...	23,901	22,119	817,547	4,317,999	180
	CHOTA NAGPORE.					
CHOTA NAGPORE.	Hazaribagh ...	7,021	6,703	150,493	771,875	110
	Lohardagga ...	12,044	6,486	240,843	1,237,123	103
	Singbhoom ...	4,503	3,208	84,416	415,023	92
	Maunbhoom ...	4,914	6,368	195,665	995,570	203
	Tributary Mehals ...	15,419	3,001	80,870	405,980	26
	TOTAL FOR CHOTA NAGPORE	43,901	25,766	752,287	3,825,571	87

Area and Population of the Several Provinces of Bengal.

Province.	Area in Square Miles.	Total Population.	Average Number of Souls per Square Mile.
Bengal (excluding Soonderbuns) ...	85,483	36,769,735	430
Behar	42,417	19,736,101	465
Orissa	23,901	4,317,999	180
Chota Nagpore	43,901	3,825,571	87
British Territory under the Lieutenant-Governor of Bengal ...	195,702	64,649,406	330
Feudatory State (Munnipore) ...	7,500	126,000	13·1
" " (Sikkim)... ...	2,600	7,000	
Total	205,802	64,782,406	......

ASSAM*

Under Chief Commissioner.

District.	Area in Square Miles.	Number of Villages, Mouzahs, or Townships.	Number of Houses.	Total Population—Male and Female.	Average Number of Souls per Square Mile.
Sylhet	5,383	5,589	286,594	1,719,539	319
Goalpara	4,433	...	72,655	444,761	100
Garo Hills	3,390	...	...	80,000	
Khasia and Jyntia Hills ...	6,157	...	...	141,838	
Naga Hills	4,900	...	...	68,918	
Kamroop	3,631	1,649	103,908	561,681	155
Durrung	3,413	137	43,558	236,009	69
Nowgong	3,648	1,293	44,050	256,390	70
Seebsaugor	2,413	203	55,604	296,589	123
Luckimpore plains	3,145	125	26,398	121,267	39
Ditto Hills	8,343				
Cachar plains	1,285	389	37,311	205,027	160
Ditto Hills	3,715				
Total	53,856	...	...	4,132,019	...

N. W. PROVINCES.

From Census Report for 1872.

Division.	District.	Area in Square Miles.	Number of Villages, Mouzahs, or Townships.	Number of Houses.	Total Population—Male and Female.	Average Number of Souls per Square Mile.
MEERUT.	Dehra Doon ...	1,020	965	24,744	116,945	114
	Saharunpore ...	2,217	1,736	197,235	884,017	399
	Moozuffernugger ...	1,659	883	155,012	690,107	416
	Meerut ...	2,360	1,573	268,650	1,276,104	541
	Boolundshuhur ...	1,910	1,566	182,694	936,667	490
	Allyghur ...	1,963	1,750	211,446	1,073,333	547
	Divisional Total ...	11,131	8,473	1,039,781	4,977,173	447

*From Bengal Census Report for 1872.

N. W. PROVINCES.—(*Continued.*)

Division.	District.	Area in Square Miles.	Number of Villages, Mouzahs, or Townships.	Number of Houses.	Total Population—Male and Female.	Average Number of Souls per Square Mile.
ROHILCUND.	Bijnour	1,902	2,002	158,583	737,153	388
	Moradabad	2,271	2,452	252,344	1,122,437	494
	Budaon	2,004	2,364	193,589	934,348	466
	Bareilly	2,982	3,548	296,441	1,507,139	505
	Shajehanpore	1,723	2,180	188,958	949,579	551
	Terai	919	591	41,732	185,658	202
	Divisional Total ...	11,805	13,137	1,131,647	5,436,314	460
AGRA.	Muttra	1,611	972	188,975	887,689	551
	Agra	1,907	1,231	231,270	1,096,367	575
	Furruckabad	1,744	3,934	190,080	918,850	527
	Mynpoori	1,696	3,750	150,888	765,845	452
	Etawah	1,691	3,529	128,707	668,641	395
	Etah	1,512	2,620	136,864	703,527	465
	Divisional Total ...	10,163	16,036	1,028,784	5,040,919	496
JHANSIE.	Jalaon	1,553	840	88,977	404,447	260
	Jhansie...	1,567	607	72,795	317,826	203
	Lullutpore	1,947	646	46,773	212,661	109
	Divisional Total ...	5,067	2,093	208,545	934,934	185
ALLAHABAD.	Cawnpore	2,336	1,985	272,232	1,156,055	495
	Futtehpore	1,585	2,741	152,777	663,877	419
	Banda	2,908	1,374	160,962	697,681	240
	Allahabad	2,747	3,503	303,900	1,396,241	508
	Humeerpore	2,286	744	121,011	529,137	232
	Jounpore	1,556	3,221	200,438	1,025,961	659
	Divisional Total ...	13,421	13,568	1,211,320	5,468,955	407
BENARES.	Azimgurh	2,565	5,071	314,327	1,531,482	597
	Mirzapore	5,217	4,104	219,059	1,015,826	195
	Benares	996	1,919	156,200	794,039	797
	Ghazeepore	2,167	3,725	285,007	1,345,570	621
	Gorruckpore	4,578	7,097	381,237	2,019,361	441
	Bustee	2,789	6,911	248,268	1,473,029	528
	Divisional Total ...	18,314	28,827	1,604,098	8,179,307	446
	Grand Total ...	69,902	82,134	6,221,175	30,037,602	430
KUMAON.	Kumaon	* 6,000	4,606	77,624	433,314	72
	Gurhwal	* 5,500	3,944	57,293	310,288	56
	Total ...	11,500	8,550	134,917	743,602	65
	Grand Total of the North-West Provinces British Districts	81,402	90,684	6,359,092	30,781,204	378

* Area Approximate.

N. W. PROVINCES.—(*Concluded.*)

Feudatory Native States.

	Area.	Total Population.
Benares (Rajah's) included in British Benares.		
Rampore*	1,140	390,232
Tehree in Gurhwal, say	445	200,000
Total	1,585	590,232
British Districts	81,402	30,781,204
Feudatory Native States	1,585	590,232
Grand Total under jurisdiction of Lieutenant-Governor, North-West Provinces	82,987	31,371,436

* Aitchison's Treaties.

PUNJAB.

From Administration Report for 1872-73.

Division.	District.	Area in Square Miles.	Number of Villages, Mouzahs, or Townships.	Number of Houses.	Total Population—Male and Female.	Average Number of Souls per Square Mile.
DELHI	Delhi ...	1,273	794	171,344	621,675	490
	Gurgaon ...	1,981	1,264	156,424	690,295	348
	Kurnal ...	2,352	913	125,321	608,942	259
	Divisional Total ...	5,606	2,971	453,089	1,920,912	343
HISSAR	Hissar ...	3,540	658	107,051	484,681	137
	Rohtak ...	1,812	436	137,458	531,227	293
	Sirsa ...	1,311	654	43,131	210,795	68
	Divisional Total ...	6,663	1,748	287,640	1,226,703	184
AMBALA	Ambala ...	2,616	2,324	243,302	1,035,488	394
	Ludiana ...	1,359	880	151,934	583.245	429
	Simla ...	18	270	7,880	33,995	1,885
	Divisional Total ...	3,993	3,474	403,116	1,652,728	414
JULLUNDUR	Jullundur ...	1,326	1,257	242,832	780,165	586
	Hoshearpur ...	2,086	21,802	209,169	939,972	450
	Kangra ...	8,389	731	147,434	743,832	83
	Divisional Total ...	11,801	23,790	599,435	2,463,969	208
AMRITSUR	Amritsur ...	1,566	1,574	198,046	832,750	535
	Sealkot ...	1,955	2,314	197,485	1,005,004	512
	Gurdaspur ..	1,818	1,880	208,256	906,126	497
	Divisional Total ...	5,329	5,768	603,787	2,743,880	515

PUNJAB.—(*Continued.*)

Division.	District.	Area in Square Miles.	Number of Villages, Mouzahs, or Townships.	Number of Houses.	Total Population—Male and Female.	Average Number of Souls per Square Mile.
LAHORE.	Lahore ...	3,670	1,455	201,536	789,662	217
	Gujranwala ...	2,558	1,202	158,270	550,576	207
	Ferozepore ...	2,692	312	119,718	549,253	204
	Divisional Total ...	8,920	2,969	472,524	1,889,491	212
RAWUL PINDI.	Rawul Pindi ...	6,212	1,658	75,579	711,256	115
	Jhelam ...	3,911	966	113,010	500,988	128
	Gujrat ...	2,037	1,428	156,195	616,361	342
	Shahpore ...	4,698	667	86,549	368,796	78
	Divisional Total ...	16,858	4,719	431,233	2,197,401	130
MOOLTAN.	Mooltan ...	5,882	1,211	111,794	471,563	80
	Jhung ...	5,709	786	74,986	348,027	61
	Montgomery ...	5,555	2,155	72,276	359,437	64
	Muzaffergarh ...	3,021	552	65,135	295,547	98
	Divisional Total ...	20,167	4,704	324,191	1,474,574	73
DERAJAT.	D. Ishmael Khan ...	7,096	716	85,100	394,864	56
	D. Ghazi Khan ...	4,186	354	62,139	308,840	133
	Banoo ...	3,150	625	60,637	287,547	91
	Divisional Total ...	14,432	1,695	207,876	991,251*	68
PESHAWUR.	Peshawur ...	2,368	654	121,456	523,152	271
	Kohat ...	2,838	343	28,639	145,419	51
	Hazara ...	2,973	1,251	75,300	367,218	122
	Divisional Total ...	8,179	2,248	125,395	1,035,789	127
	Total for Punjab British Districts ...	111,948	54,086	3,908,386	17,596,698	172
	Native Feudatory and Protected States ...	97,802	...	...	5,231,388	
	Grand Total British Districts and Native States ...	199,750	...	...	22,828,086*	

* This total does not include population of Nabha.

Area and Population of Native Feudatory States in Subordination to the Punjab Government.

Names of States.	Estimated Area.	Estimated Population.	Names of States.	Estimated Area.	Estimated Population.
Jamu and Kashmir, including Baltistan, Ladakh, &c.	63,959	1,537,000	Brought over ...	96,876	5,024,088
Patiala ...	5,412	1,586,000	Luharu ...	226	19,000
Bahawalpur ...	14,310	472,791	Dujana ...	12	27,000
Jhind ...	1,236	189,475	Baghat ...	32	10,000
Nabha ...	863	......	Bhagal ...	12	22,000
Kapurthala ...	598	227,155	Jubbul ...	242	40,000
Mandi ...	1,080	253,293	Kumharsan ...	80	10,000
Sarmur (Nahan) ...	1,000	135,000	Bhajji ...	74	19,000
Kahlur (Belaspur) ...	367	90,000	Mailog ...	45	9,000
Bassahir ...	3,064	60,000	Balsan ...	45	6,000
Hindur (Nalagarh) ...	234	90,000	Dhami ...	27	5,500
Keonthal ...	89	70,000	Kuthar ...	21	4,000
Maleir Kotla ...	165	50,000	Kumhiar ...	9	2,500
Faridkot ...	613	46,200	Mangal ...	14	800
Chamba ...	3,215	110,000	Bija ...	6	800
Suket ...	420	44,966	Darkuti ...	2	700
Kalsia ...	168	62,000	Taroch ...	64	10,000
Pataodi ...	53	20,208	Sangri ...	14	700
			Ratesh ...	1	300
Carried over ...	96,876	5,024,088	Total for Native Feudatory States Punjab ..	97,802	5,231,388*

* This Total does not include the population of Nabha.

OUDE.

From Administration Report for 1872-73.

Division.	District.	Area in Square Miles.	Number of Villages, Mouzahs, or Townships.	Number of Houses.	Total Population—Male and Female.	Average Number of Souls per Square Miles.
LUCKNOW.	Lucknow ...	988	956	138,310	789,460	799
	Unao ...	1,764	1,754	201,528	945,955	536
	Bara Banki ...	1,769	2,093	247,866	1,115,253	627
	Divisional Total ...	4,521	4,803	587,704	2,850,668	654
SITAPUR.	Sitapur ...	2,206	2,359	171,030	921,107	433
	Hardui ...	2,292	1,961	180,590	931,377	406
	Kheri ...	3,046	1,777	197,658	738,604	242
	Divisional Total ...	7,544	6,097	549,278	2,591,088	360
FYZABAD.	Fyzabad ...	1,681	2,568	185,647	1,022,770	608
	Bhairaich ...	2,710	1,965	153,007	774,640	286
	Gonda ...	2,745	2,834	217,999	1,166,515	425
	Divisional Total ...	7,136	7,367	556,653	2,963,925	439

OUDE.—(*Continued.*)

Division.	District.	Area in Square Miles.	Number of Villages, Mouzahs, or Townships.	Number of Houses.	Total Population—Male and Female.	Average Number of Souls per Square Mile.
RAI BAREILLY.	Rai Bareilly ...	1,741	1,768	247,259	988,636	536
	Sultanpur ...	1,704	2,526	222,401	995,816	584
	Pratabgarh ...	1,423	2,209	156,776	784,154	543
	Divisional Total ...	4,868	6,503	626,436	2,768,606	569
	Grand Total for Province ...	24,069	24,770	2,320,071	11,174,287	464

CENTRAL PROVINCES.

From Census Report, 1872.

Division.	District.	Area in Square Miles.	Number of Villages, Mouzahs, or Townships.	Number of Houses.	Total Population—Male and Female.	Average Number of Souls per Square Mile.
NAGPORE.	Nagpore ...	3,734	1,657	121,119	631,109	169·02
	Bhandara ...	3,922	1,589	106,121	564,813	144·01
	Chanda ...	9,700	2,392	108,258	534,431	55·10
	Wardha ...	2,379	893	75,145	354,720	149·10
	Balaghat ...	2,608	781	37,192	195,008	74·77
	Divisional Total ...	22,343	7,312	447,835	2,280,081	102·05
JABALPORE.	Jabalpore ...	3,918	2,281	114,862	528,859,	134·98
	Sagor ...	4,005	1,858	98,777	527,725	131·77
	Dumoh ...	2,799	1,128	57,688	269,642	96·34
	Seoni ...	3,606	1,6[illegible]	79,043	407,330	112·96
	Mandla ...	4,719	1,595	44,913	213,018	45·14
	Divisional Total ...	19,047	8,523	395,283	1,946,574	102·29
NERBUDDA.	Betul ...	4,118	1,150	53,234	284,055	68·98
	Chindwara ...	3,916	1,723	[illegible],819	316,095	80·72
	Hoshungabad ...	4,222	1,286	87,463	440,186	104·26
	1 Feudatory State ...	215	57	2,704	13,648	63·48
	Narsingpur ...	1,916	979	64,888	339,395	177·14
	Nimar ...	3,340	648	42,164	211,176	63·23
	Divisional Total ...	17,727	5,843	312,272	1,604,555	90·51.

CENTRAL PROVINCES.—(*Continued.*)

Division.	District.	Area in Square Miles.	Number of Villages, Mouzahs, or Townships.	Number of Houses.	Total Population—Male and Female.	Average Number of Souls per Square Mile.
CHATESGURH.	Raipoor	11,885	4,431	241,922	1,093,405	92·00
	4 Feudatory States ...	2,658	1,500	67,528	343,850	129·36
	Total	14,543	5,931	309,450	1,437,255	98·83
	Bilaspoor	7,798	3,366	170,237	715,398	91·74
	2 Feudatory States ...	1,002	450	22,346	83,856	83·69
	Total	8,800	3,816	192,583	799,254	90.82
	Sambalpore	4,407	1,710	98,166	523,034	118·68
	7 Feudatory States ...	11,897	4,597	125,991	529,700	44·51
	Total	16,304	6,307	224,157	1,052,534	64·56
	Total Khalsa	24,090	9,507	510,325	2 331,837	96·80
	„ Feudatory	15,557	6,547	215,865	957,206	61·52
	Divisional Total	39,647	16,054	726,190	3,289,043	82·96
	Upper Godavery District ...	1,971	427	11,280	52,120	26·44
	1 Feudatory State ...	13,062	1,659	41,600	78,856	6·04
	Total	15,033	2,086	52,880	130,976	8·71
	Grand Total British Territory	84,963	31,555	1,674,291	8,201,519	96·53
	Ditto Feudatory	28,834	8.263	260,169	1,049.710	36·41
	Provincial Total	113,797	39,818	1,934,460	9,251,229	81·30

MADRAS PRESIDENCY.

From the Administration Report for 1872-73.

District.	Area in Square Miles.	Number of Villages, Mouzahs, or Townships.	Number of Houses.	Total Population—Male and Female.	Average Number of Souls per Square Mile.
Ganjam* ...	8,313	4,562	341,404	1,520,088	183
Vizagapatam† ...	18,344	8,581	489,419	2,159,199	118
* Godavery ...	6,224	2,202	389,712	1,592,939	256
Kistna ...	8,036	2,140	282,358	1,452,374	181
Nellore ...	8,462	2,417	263,820	1,376,811	163
Carried over ...	49,379	19,902	1,766,713	8,101,411	

* Includes chiefships of Bodogodo, &c.
† Includes Jeypore and its dependencies.

MADRAS PRESIDENCY.—(*Continued.*)

District.	Area in Square Miles.	Number of Villages, Mouzahs, or Townships.	Number of Houses.	Total Population —Male and Female.	Average Number of Souls per Square Mile.
Brought over ...	49,379	19,902	1,766,713	8,101,411	
Cuddapah ...	8,367	1,337	339,063*	1,351,194	162
Bellary ...	11,007	2,540	351,943	1,668,006	152
Kurnool ...	7,358	787	205,884	959,640	130
Chingleput ...	2,753	2,362	141,434	938,184	341
North Arcot ...	7,139	5,292	329,844	2,015,278	282
South Arcot ...	4,878	3,198	228,761	1,755,817	360
Tanjore ...	3,654	3,935	369,984	1,973,731	540
Trichinopolly ...	3,515	1,644	210,690	1,200,408	342
Madura ...	9,502	5,459	443,513	2,266,615	239
Tinnevelly ...	5,176	1,824	403,803	1,693,959	327
Coimbatore ...	7,432	1,575	361,109	1,763,274	237
Nilgiris ...	749	17	13,922	49,501	66
Salem ...	7,483	4,021	391,519	1,966,995	263
South Canara ...	3,902	1,288	184,569	918,362	235
Malabar ...	6,002	432	435,462	2,261,250	377
Madras City ...	27	23	51,741	397,552	14,724
Total ...	138,318	55,636	6,22[illegible],954	31,281,177	226

NATIVE STATES—MADRAS PRESIDENCY.

State.	Area in Square Miles.	Estimated Total Population.
Travancore	6,653	1,500,000
Cochin	1,131	399,060
Puducottah	1,380	316,695
Bunganpully (Cuddapah)	500	85,200
Sundoor (Bellary)	145	13,446
Ali Rajah (Cannanore and S. Lacadive Islands) ...	9,446	1,000
Total ...	19,255	2,265,401

BOMBAY PRESIDENCY.

From Administration Report for 1872-73.

Division.	District.	Area in Square Miles.	Number of Villages, Mouzahs, or Townships.	Number of Houses.	Total Population—Male and Female.	Average Number of Souls per Square Mile.
NORTHERN DIVISION.	Ahmedabad ...	3,844	881	260,970	829,637	216
	Bombay city ...	22	...	29,691	644,405	29,291
	Kaira ...	1,561	591	218,596	782,733	501
	Broach ...	1,363	425	96,723	350,322	257
	Panch Mehals ...	1,731	719	56,922	240,743	139
	Surat ...	1,588	859	159,367	730,936	442
	Khandesh ...	10,162	3,447	229,899	1,028,642	101
	Nasik ...	8,116	1,449	133,848	734,386	91
	Tanna ...	4,052	...	148,161	847,424	209
	Kolaba ...	1,482	1,064	72,699	350,405	236
	Divisional Total ...	33,921	...	1,406,876	6,539,633	194
SOUTHERN DIVISION.	Ahmednagar ...	6,647	1,370	141,652	773,938	116
	Poona ...	4,983	1,202	142,687	907.235	182
	Satara ...	5,378	1,420	172,513	1,116,050	208
	Ratnagarhi ...	3,789	1,337½	224,790	1,019,136	269
	Sholapur ...	3,899	647	109,826	662,986	170
	Kaladgi ...	5,695	1,204	143,704	816,037	143
	Belgaum ...	4,591	1,132	188,177	938,750	204
	Dharwar ...	4,565	1,436	205,072	988,037	216
	Kanara ...	4,235	1,067	91,593	398,406	94
	Divisional Total ...	43,782	10,815½	1,422,014	7,620,575	174
SINDH.	Upper Sindh ...	1,913	1,009	18,969	89,985	47
	Shikarpore ...	8,809	5,236	144,085	776,227	88
	Hydrabad ...	9,635	915	147,078	721,947	75
	Karachi ...	14,089	711	97,824	423,495	30
	Thurr and Parkar ...	12,729	1,750	39,692	180,761	14
	Divisional Total ...	47,175	9,621	647,648	2,192,415	46

BOMBAY PRESIDENCY—NATIVE STATES.

Division.	Native State.	Area in Square Miles.	Estimated Total Population.
Feudatory Native States.	Katch, exclusive of Runn ...	6,500	500,000
	Pahlanpur	2,700	500,000
	Mahi Kanta	4,000	447,056
	Kathiawar	20,000	2,321,833
	Baroda	5,399	2,600,000
	Rewakanta	4,879	487,647
	Jinjira	324	72,000
	Sattara Jaghirs	1,950	300,870
	Akalkot	498	81,068
	Kolhapur	3,184	802,691
	Southern Mahratta Jaghirs	Unknown.	610,434* 14,719†
	Carried over ...	49,434	8,738,318

Division.	District.	Area in Square Miles.	Estimated Total Population.
	Brought over ...	49,434	8,738,318
Feudatory Native States.	*Petty Principalities under*		
	Panch Mehal ...	143	6,837
	Kambay	350	83,494
	Surat	Not known.	....
	Suchen	Ditto.	15,606
	Kandesh, Dang	1,000	19,000
	Surghana	360	8,023
	Mehwasi Tracts ...	....	6,780
	Savanur	66	17,179
	Nasik Peint	850	47,033
	Jawar	534	37,406
	Grand Total of Native Feudatory States in Bombay Presidency	52,737	8,979,676

* In Native State. † In British Territory.

HYDERABAD.

Nizam's Dominions.

	Area in Square Miles.	Total Population.	Average Number of Souls per Square Mile.
Nizam's dominions	97,837*	10,500,000	107·3

* Hyderabad Survey Report.

BERARS EAST AND WEST.

HYDERABAD ASSIGNED DISTRICTS.

From Administration Report for 1872-73.

District.	Area in Square Miles.	Number of Villages, Mouzahs, or ownships.	Number of Houses.	Total Population —Male and Female.	Average Number of Souls per Square Mile.
Akola ...	3,396	1,344	163,579	619,134	191
Mehkur ...	3,013	967	71,288	353,436	117
Oomraoti ...	2,643	911	87,841	407,276	151
Woon ...	5,510	1,634	99,308	477,361	86
Ellichpoor ...	1,122	514	66,333	303,953	270
Melghat ...	1,650	824	7,411	40,405	24
Total ...	17,334	5,694	495,760	2,231,565	128

MYSORE AND COORG.†

From Administration Report for 1872-73.

Division.	Districts.	Area in Square Miles.	Number of Villages, Mouzahs, or Townships.	Number of Houses.	Total Population —Male and Female.	Average Number of Souls per Square Mile.
NANDI-DROOG.	Bangalore ...	2,914	5,508	176,621	828,354	284
	Kolar ...	2,576	5,580	165,892	618,954	240
	Tomkoor ...	3,608	4,996	123,401	632,239	178
	Divisional Total ...	9,098	16,084	465,914	2,079,547	229
ASHTA-GRAM.	Mysore ...	4,052	4,741	174,951	943,187	233
	Hassan ...	3,292	5,155	147,243	668,417	203
	Divisional Total ...	7,344	9,896	322,144	1,611,604	220

† *Note.*—The first two columns have been taken from Administration Report for 1871-72, the rest from the Administration Reports of Mysore and Coorg for 1872-73. The area of Mysore obtained from Topographical Survey by Colonel Mackenzie—1800—1807.

MYSORE AND COORG.—(*Continued.*)

Division.	District.		Area in Square Miles.	Number of Villages, Mouzahs, or Townships.	Number of Houses.	Total Population—Male and Female.	Average Number of Souls per Square Mile.
NAGAR.	Shemoga	...	3,798	4,016	101,959	498,976	131
	Kadur	...	2,294	3,075	75,856	333,925	146
	Chitlledroog	...	4,470	2,147	118,558	531,360	119
	Divisional Total	...	10,562	9,238	296,373	1,364,261	129
	Total for Mysore	...	27,004	35,218	1,084,481	5,055,412	187
	Ditto Coorg	...	2,400	...	...	168,312	70

CENTRAL INDIA OR INDORE AGENCY.

State.		Area in Square Miles.	Estimated Population.	State.		Area in Square Miles.	Estimated Population.
				Brought over	...	...	...
Sindia	...	not given.	2,500,000				
Holkar	...	8,318	576,000	Peploda	...	not given.	not given.
Bhopal	...	6,764	663,656	Jobut	...	„	7,000
Dhar	...	2,091	125,000	Alirajpore	...	1,500	55,000
Dewas	...	256	25,000	Jhabua	...	1,500	60,000
Jowrah	...	872	85,456	Burwani	...	2,000	30,000
Ratlam	...	500	91,839	Muttewah	...	not given.	not given.
Silana	...	103	88,978	Khuttewarra	..	„	„
Sitamhow	...	not given.	20,000	Ruttonmai	...	„	„
Punthpeeplode	...	„	not given.	Bundlecund States	...	16,312	1,638,847
Carried over	...	...	...			...	...

The estimated total area of the Central India or Indore Agency is 83,600 Square Miles. Estimated Population 7,670,000.

NATIVE STATES, BUNDLECUND AGENCY.—(CENTRAL INDIA AGENCY.)

From Aitchison's Treaties and Sunnuds, Vol. III.

Native State.	Estimated Area in Square Miles.	Estimated Population.	Native State.	Estimated Area in Square Miles.	Estimated Population.
			Brought over ...	4,735	483,800
Punnah ...	688	67,500	Behut	15	2,500
Logassi ...	30	3,500	Alipoora	85	9,000
Chirkari ...	880	81,000	Kotee	450	70,000
Bijwari ...	920	90,000	Sohawal	300	50,000
Ajaigarh ...	340	50,000	Gouhar	76	7,500
Surula ...	35	4,500	Gerowli	50	5,000
Jignee ...	27	2,800	Myhere	400	70,000
Jussoo ...	180	24,000	Baonee	127	19,000
Behree ..	30	2,500	Hush Bya Jughirs ...	85	18,000
Chatturpur ...	1,240	120,000	Kunnayadhana ...	......	6,000
Bironda ...	275	24,000	Rewah	*10,019	898,047
Chobey Jaghires ...	90	14,000			
Carried over ...	4,735	483,800	Total ...	16,342	1,638,847

* From Rewah Survey Report.

RAJPOOTANA AGENCY.

From Aitchison's Treaties.

State.	Estimated Area in Square Miles.	Estimated Population.	State.	Estimated Area in Square Miles.	Estimated Population.
Oodeypore or Meywar	11,614	1,161,400	Brought over ...	98,551	14,478,000
Jeypore ...	15,000	1,900,000			
Jodhpore or Marwar	35,672	1,783,600	Jessulmere ...	12,252	73,700
Boondee ...	2,291	220,000	Serohi ...	3,000	55,000
Kotah ...	5,000	433,000	Doongurpore ...	1,000	100,000
Tonk ...	1,800	182,000	Banswara ...	1,500	150,000
Kerowli ...	1,878	188,000	Partabgarh ...	1,460	150,000
Kishengarh ...	720	70,000	Jhallawar ...	2,500	220,000
Dholepore ...	1,626	500,000			
Bhurtpore ...	1,974	6,501,000			
Ulwar ...	3,300	1,000,000			
Bekaneer ...	17,676	530,000	Total Native States under Rajpootana Agency ...	120,263	9,375,700
Carried over ...	98,551	14,478,000	Ajmere & Mhairwarra (British District)...	*2,660	316,590

* From Administration Report for 1872-73.

PORTUGUESE TERRITORY.

From Bombay Administration Report for 1873.

District.	Estimated Area in Square Miles.	Population.	Number of Persons per Square Mile.
Goa ...	*1,212	363,788	...
Damaun ...	22	6,000	...
Diu ...	1¾		
Total ...	1,235¾	369,788	342

* Gerling's Survey Report.

FRENCH POSSESSIONS.

Area and Population.

District.	Estimated Area in Square Miles.	Estimated Total Population.
Chandernagore ...	37	...
Karical ...	522	32,679
Pondicherry ...	1,124	171,217
Yanaon ...	56	...
Mahe ...	228	...
8 small plots in various Provinces ...	1	...
Total ...	1,968	...

BRITISH BURMA.

Administration Report for 1872-73.

Division.	District.	Area in Square Miles.	Number of villages, Mouzahs, or Townships.	Number of Houses.	Total Population—Male and Female.	Number of Persons per Square Mile.
ARRACAN.	Akyab ...	5,944	1,800	59,375	268,112	5
	Ramree ...	4,080	915	26,005	129,284	31
	Sandoway ...	3,667	404	10,655	48,467	13
	Northern Arracan ...	4,839	177	2,009	7,062	2
	Divisional Total ...	18,530	3,329	98,044	452,925	25
PEGU.	Rangoon ...	9,800	1,581	78,121	350,312	36
	Bassein ...	8,954	1,554	64,705	304,683	34
	Myanoung ...	4,150	2,414	82,583	435,323	105
	Prome ...	2,225	1,064	58,676	251,455	69
	Theyetmyo ...	3,275	822	29,016	126,121	69
	Divisional Total ...	28,404	7,435	313,081	1,467,894	52
TENNASSERIM.	Tonghoo ...	6,354	650	19,986	78,406	13
	Shewgween ...	10,272	775	28,918	141,503	14
	Amherst ...	15,144	556	38,072	235,747	16
	Tavoy ...	7,200	227	12,556	70,499	10
	Mergui ...	7,760	182	8,152	44,762	6
	Divisional Total ...	46,730	2,390	107,684	570,917	12
	Grand Total for British Burmah ...	93,664	13,151	518,809	2,491,736	27

Total Area and Population of BRITISH INDIA *and* FEUDATORY STATES.

Province.	British Districts.			Native Feudatory States.			Total.		
	Area in Square Miles.	Total Population.	Number of Souls per Square Mile.	Estimated Area.	Estimated Population.	Number of Souls per Square Mile.	Area.	Population.	Number of Souls per Square Mile.
Bengal Presidency. Bengal*	195,702	64,649,406	330	10,100	133,000	17	205,802	64,782,406	315
Bengal Presidency. Assam	53,856	4,132,019	42	....	....	....	53,856	4,132,019	42
Bengal Presidency. N. W. Provinces	81,402	30,781,204	378	1,585	590,232	372	82,987	31,371,436	378
Bengal Presidency. Punjab	111,948	17,596,698	172	97,802	5,231,388	....	209,750	22,828,086	114
Bengal Presidency. Oudh	24,069	11,174,287	464	....	....	....	24 069	11,174,287	....
Bengal Presidency. Central Provinces	84,963	8,201,519	97	28,834	1,049,710	36	113,797	9,251,229	81
Madras Presidency	138,318	31,281,177	226	19,255	2,265,401	....	167,513	33,546,578	200
Bombay Presidency, including Sindh	124,878	16,352,623	131	52,737	8,979,676	170	177,615	25,332,299	143
Hyderabad (Nizam's)	....	....	....	97,837	10,500,000	107	97,837	10,500,000	107
Assigned Districts Berars (East and West)	17,334	2,231,565	128	....	....	....	17,334	2,231,565	128
Mysore	....	....	....	27,004	5,055,412	164	29,404	5,223,724	177
Coorg	2,400	163,312	....	....	....	....			
Central India Agency	....	....	....	83,600	7,670,000	71	83,600	7,670,000	71
Rajpootana Agency with Ajmere & Mhairwarra	....	....	....	120 263	9,375,700	77	122,923	96,912,290	77
	2,660	316,590	297	....	....	....			297
Portuguese Territory	....	....	....	1,236	369,788	339	1,236	369,788	339
French Territory†	....	....	....	1,968	....	....	1,968	....	....
British Burma, including Tenasserim	93,664	2,491,736	27	....	....	....	93,664	2,491,736	27
	928,794	189,208,824	204	544,621	51,388,619	94	1,473,415	240,597,443	163
Independent.									
Nepaul (Estimated)	....	....	....	54,000	5,600,000	104			

* Excluding the Soonderbuns, of which the estimated area is 5,341 square miles—Population unknown.
† Excluding French Population of French Territory.

Part IV.

CHAPTER I.

Route Surveying and Military Reconnoissance.

Route Surveys, although they do not come under the head of scientific or accurate works, can, however, be made to approximate so near the truth, as to become very useful in filling in the topography of countries that have not come under more detailed operations.

Military Reconnoissance may be said to form a part of Route Surveying, for the latter, in a military point of view, would be of little use without the former, and a sketch of the country combined with an explanatory statistical report, constitutes what is called a Military Reconnoissance, and in which the importance of the *sketch* or the *report* predominates according to circumstances.

This duty is generally performed in India by the Quarter Master General's Department, but opportunities are numerously afforded to many other Officers in this country, of obtaining information of various kinds, which might be eventually useful to the Government in one way or other.

"The object for which any reconnoissance is undertaken naturally suggests the points to which the attention of the Officer should be principally directed; if, for example, it is merely to determine the best line of march for troops through a friendly or undisputed country, the state of the communications, the facilities of transport, and possibility of provisioning a stated number of men upon the route, are the first objects for his consideration. If the ground in question is to be occupied either permanently, or for temporary purposes, or if it is likely to become the seat of war, his attention must be directed to its military features; and a sketch of the ground, with explanatory references, together with a full and correct report of all the intelligence he can collect from observation, or from such of the inhabitants as are most likely to be well acquainted with the localities, and most worthy of credence, will demand the exertion of all his energies; upon the correct information furnished by this reconnoissance may depend, in a great measure, the fate of the army."*

Despatch and simplicity of execution are the great things to be aimed at in a military sketch, and although the greatest possible accuracy may not be altogether necessary, yet every precaution should be taken as far as circumstances will admit. Its objects being so different from the more operose surveying, the shortest, easiest and most certain methods of practice will ever be entitled to the greatest attention.

* Frome on Surveying.

The principles of military sketching cannot differ essentially from those of surveying; they both consist in determining the sides and angles of real or imaginary figures upon the surface of the earth; these can always be resolved into triangles, by means of which we lay down these figures upon paper to any required scale. But the *practice* differs very considerably, and it is for this reason that they are called sketches rather than surveys, because so much of them is usually done by the eye, instead of being a continued series of angles and measured lines, as in the more elaborate surveys. Many instruments have been contrived for military sketching, each of which has some advantage peculiar to itself, but the prismatic compass and pocket sextant, as described in pages 51 and 81, appear to be the best adapted for this kind of work.* To these must be added a case of leather to hold the sketches, and an ivory protractor together with a pencil, and which are generally contained in the sketching case, to lay down the angles and the distances.

One of the most essential things to be acquired is that of judging distances with accuracy; upon this every thing depends in a hasty sketch where instruments are sparingly used or excluded altogether. A few days' practice will enable an Officer to estimate, with tolerable accuracy, the length and average quickness of his ordinary pace, as also that of his horse, as on a rapid reconnoissance he must necessarily be mounted, and the habit of guessing distances, which can afterwards be verified, will tend to correct his eye.

An easy mode of judging distances is by marking on a scale or pencil, held at some fixed distance from the eye, the apparent diameter, or height, at different measured distances, of any objects the dimensions of which may be considered nearly constant, such as the average height of a man, a house of one or two stories, &c.

"The degree of accuracy of which a military sketch is susceptible, depends upon the time that can be allowed, and the means that may be at hand. If a good map of the country can be procured, the positions of several conspicuous points can be taken from it and laid down on the required scale; or a rough base may be measured, carefully paced, or obtained from some known distance, and angles taken with a pocket sextant or other instrument from its extremities, to form a tolerably accurate species of triangulation, which may be laid down without calculation, and within this the detail can be sketched more rapidly, and with far more certainty than without such assistance. No directions that can possibly be given will render an Officer expert at this most necessary branch of his profession, as practice alone can give him an eye capable of generalizing the minute features of the ground, and catching their true military character, or the power of delineating them with ease, rapidity, and correctness."†

* The "Omnimeter," page 74, "Stadiometer," page 126, and "Subtense Theodolite," page 132, are also well suited for rapid Surveys, Military Reconnoissance and Exploration.

† Frome on Surveying.

The adjoining Plate represents the form of a report extracted from "Major Jackson's Course of Military Surveying;" and which should accompany all Route Surveys. This form was drawn up by Major Hector Straith, late Professor of Fortification, at the Honorable Company's Military Seminary at Addiscombe. It is the result of his own observations when serving in India, and is well suited to the purpose.

The limits of this work will not admit of our pursuing this interesting subject any further, but the following memoranda, extracted from the same work, which are nearly transcripts of those issued by Sir George Murray, for the guidance of the Officers of the Quarter Master General's Department, during the Peninsular War, will serve to point out the principal objects to which an Officer employed in the important duty of reconnoitring, should direct his attention.

He must seek to acquire a good general knowledge of the country upon which he is to report, regarding its natural and political divisions, and principal features. He will then go into detail, dividing the subject into different heads, as :—

I.—The peculiar nature of each district of country, and its productions.

Particularizing what parts of it are mountainous or hilly, and what are level: whether the hills are steep, broken by rocky ground, rise by gradual and easy slopes; or if the ground is undulated only in gentle swells. Whether the connexion of the high lands is obvious and continued, or if the heights appear detached from each other. In what directions the ridges run, and which are their steepest sides. The nature and extent of their vallies and ravines—where they originate, in what directions they run, whether difficult of access, or easy to be passed.

Whether the country is barren or cultivated, and what is the kind of cultivation—whether vines, or olives, or corn; and if the latter, what kinds of corn are grown; and in what parts it is most abundant. If a country of pasturage, whether it is grazed by cattle, by sheep, or by horses, and in what numbers. What parts of the country are open, and what are enclosed, and the description of the enclosures—whether small or extensive, formed by stone walls, ditches, hedges, or fences of any other kind. What parts of the country are wooded, and whether with grown timber, or coppice wood; and with what species of trees—what the nature of the soil.

What is the nature of the country, in reference to the operations of troops—what parts of it are favorable for the acting of cavalry, and what for infantry only.

II.—The rivers and minor streams, and canals.

The sources of rivers, and the direction of their course—whether they are rapid or otherwise; their breadth and depth, and what variations they are subject to, at different seasons of the year—the nature of their channels and of their banks—whether rocky, gravelly, sandy, or muddy—of easy or of difficult access: the bridges across them—whether of stone or of wood; their breadth and length; if accessible to artillery, and capable of bearing its weight. The nature of the fords, if always passable, or at certain times and seasons only—whether their situations change.* What rivers are navigable, and from and to what points, and by what description of vessels or boats. The ferries—their breadth, and the nature of the landing-place on each side; what description of boats are used at them—how many men, horses, or carriages, each boat is capable of conveying—how much time the passage requires, and in what manner it is performed. Canals—their course, breadth and depth; the nature of the traffic carried on upon them—the number of boats usually to be found at different places, and the nature and dimensions of the boats; also, whether they are tracked by men or horses, or how otherwise navigated. Lakes and inlets of the sea—their situation, extent, and boundaries; what description of vessels can navigate them, &c., together with such of the above observations as are applicable to them. Marshes—their situation and extent—whether passable for troops in any part; and if they continue throughout the year, or exist only during the wet season.

III.—Populations, resources, accommodation for troops, &c.

The size of towns and villages, and the number of their inhabitants; and whether well supplied with provisions, or not. The number of houses as also of churches, convents, or other public buildings—whether the houses are large and commodious, or small and mean—what number of troops could be accommodated in private houses, and what in public buildings, what stabling there is, or other cover for horses—if the town is walled or open, favourably situated for defence, or otherwise—if capable of being strengthened, and by what means. Similar observations in regard to detached convents, gentlemen's seats, farms, and other separate buildings. Plans or sketches of walled towns, defensible villages, or detached buildings, should always accompany the reports upon them. The number of carriages, horses, mules, or draught oxen, in possession of each town, village, or farm, should be stated; and what

* A ford should not exceed in depth 3 feet for infantry, 4 feet for cavalry, and 2½ feet for artillery.

is the general means of conveyance made use of in the country—what mills exist in the town or vicinity, and whether turned by wind or water; the bake-houses, and quantity of bread they can produce in a given time; whether the place is unhealthy, or not, if it be whether it is in general unhealthy, or only so at particular seasons.

IV.—Roads.

Particular information must be obtained respecting the roads, in the description of which it is impossible to be too minute; the general nature of each road, as also the variations which occur in it, from distance to distance, should be accurately described—whether the road has been regularly made, or appears to have been formed only by the use of the people of the country; whether it is fit for artillery, or practicable for any description of wheel-carriage: for cavalry, or for infantry only—over what description of soil it passes; whether rocky, or gravelly; sandy, clayey, or earthy; and to what injuries it is liable in bad weather; whether it is easily repairable or not, what materials are requisite for that purpose, and whether they are to be found in the neighbourhood; whether any bad parts of the road, or the narrow and embarrassed streets of any of the towns or villages, can be avoided, by going out of the road for a short distance; as, also, whether any great improvement could be made in the general direction of any part of the road, by adopting a new line altogether for a considerable distance; and what work is necessary in either of these cases. Particular attention should be paid to the ascents and descents upon the road; whether they are gradual and easy, or abrupt, rugged, or stony, having short turns or other difficulties; whether the road is wide enough in those parts which go along the side of a hill, and whether it is even, or is canted off the level, so as to be unsafe for carriages. In those parts where the road passes between walls, or where it forms a hollow way between banks of earth, rocks, or other obstacles, its breadth ought to be measured, and it should be remarked also whether it can be widened or the obstacles removed which confine it. The ferries, bridges, fords, &c., met with upon the road, should be particularly described; the possibility of obstructing or breaking up the road, so as to prevent its being used by the enemy; or of destroying the bridges or fords upon it should be stated. The means of effecting these objects should be pointed out; as also the labor and time requisite for such a work. The distances of the places along the road should be given, both in the measures of the country, and in English miles, averaged as accurately as possible. The time required to travel the different distances (at the ordinary walk of a man, or of a

horse) should also be stated. The places to the right and left, near the road should be mentioned; their distances from the road, and at what points the communications to them strike off. Whether there are any railroads, and what facilities they offer for the rapid transport of troops, artillery, provisions, &c.

Care must be taken that the names of towns, villages, rivers, &c., are spelt in the same manner as by the natives of the country, and when the spelling and the pronunciation differ very much, the name should also be written (in a parenthesis) as it is pronounced.

V.—Camps and Positions.

All strong passes, posts, or more extensive positions, which present themselves either upon the line of a road, or in any other situation; as also all places favorable for encamping or bivouacking troops, either with a view to position, or with reference merely to convenience upon a march, should be particulary described—their situation, extent, facility of access, nature of soil, supply of water at all seasons, quantity and kind of wood, and whether in sufficient abundance for hutting the troops, or only for furnishing fuel. A sketch of the ground upon a pretty large scale should always accompany these reports.*

In all reports, officers should state distinctly what parts of the information they contain rest upon their own personal examination of the objects in question, and what upon the authority of others; and, in the latter case, they should mention the source of their information, in order that a judgment may be formed of the degree of credit to which it is entitled.

Sketches of the above character may be, and frequently are, rendered extremely useful, when time and opportunity permit nothing better, but in India, where such vast tracts of country are almost totally unexplored, the Officers of the Engineer and Quarter Master General's Department are constantly employed in time of peace in performing Route Surveys which partake of a higher order, and are carried on with good instruments, and in the absence of all trigonometrical closing points, are checked by astronomical observations made with a reflecting circle or sextant, and an artificial horizon.

These surveys form our first geographical knowledge of all new countries, which are either annexed to, or under the protection of, British rule. It therefore is of the greatest importance that they be conducted

* Sketches of positions should never be made upon a smaller scale than four inches to an English mile. More general sketches may be made upon a scale of two inches to a mile, and tracings of roads upon a scale of one inch to a mile.

with some sort of system, that the materials may be compiled and put together in such a way as to be useful in a general map. It will not do to commence from the peg of your tent or other indefinite object; every route should start from a fixed and well-known permanent point of departure, and close on similar objects, such as temples, mosques, pucka buildings or churches. This point of departure should be fixed either trigonometrically or astronomically, and if no such points are available at the time, they ought to be fixed as soon after as possible. If bits here and there are surveyed indiscriminately, without points of departure and closure, and without connection with themselves or with other people's work, gaps here and overlapping there, nothing but confusion can ensue. If in a campaign or line of march, the Surveyors start in the dark, and do not survey until the day dawns, all the ground traversed in the *interim* becomes an hiatus; *then* a route may be measured with vast accuracy, angles repeated and the greatest refinement observed, until the sun gets hot, when the survey stops in the middle of the road, and the Surveyor gallops home.

In this way many maps, of recently explored tracts, have been constructed, partly by guess and partly by measurement; to practical Surveyors, this may appear absurd, but such things, nevertheless, have been done.

The staple commodity for route, or Road Surveyors, is the perambulator. A few words, therefore, regarding this most useful and necessary instrument will not be out of place. In the first place, all English perambulators should be condemned *in toto*, they are flimsy, bad in principle, and incapable of working, except on a smooth road or bowling green; across country they go to pieces in a mile or two. There is nothing like the Madras pattern principle of the endless screw and differential plates. The large Madras perambulator, (page 47,) however, has two faults, the wheel is not sufficiently strong, and it is graduated to furlongs and yards, which is unscientific. Colonel Waugh's 10 mile perambulator (page 48,) with decimal scale, is a very handy and accurate implement, and will stand any hard usage; the wheel is constructed on gun-carriage principles, and the tire of strong iron is put on hot, and chilled on tight, so that the structure is firm in the extreme. The Surveyor General of India has also invented an instrument running 20 miles on the same principle, and graduated decimally, which is much approved of; the errors of perambulators should always first be tested by running them along one or two sides of a large triangle of the Trigonometrical Survey and comparing the values.

We have already described (Part III, Chap. III,) the usual method of surveying a road, commonly called traversing; the same system precisely prevails for the illustration of the details on any line of country through which it may be required to carry a road, canal, or the like, and of which the general line, or the difference of latitude and longitude of various points is sought, care being taken to adopt as many checks as possible during the progress of the survey to prevent errors, viz., by different parties running independent routes and closing on each other's work every day, or by reverse operations, and by intersections at every convenient station; for the several bearings on the same object should, in the plotting, meet at a common point of intersection. These, and astronomical observations are the only means by which a route survey can be checked. The method of plotting a survey or that of protraction by co-ordinates, has already been shown (Part III, Chap. VIII,) and the manner of adapting this for routes cannot be better explained than by transcribing an excellent example from Captain Boileau's Traverse Tables.

"The annexed Table contains an extract from a survey, by myself, of the road between HATRAS and BAREILLY, in the N. W. Provinces of the Bengal Presidency, made in the year 1836, and will serve to illustrate the application of the Tables (Note page 235) to this kind of work. The first column refers to the numbers of the stations; the second, to the names of the villages or towns immediately contiguous to the lines, or through which they may pass, and prevents the necessity of frequent reference to the Field-book; in the third column are entered the true bearings, as registered on the limb of the theodolite, *i.e.*, the observed magnetic bearings, corrected for the variation of the compass; columns four to the end are, in all respects, similar to those in the Table (page 243), and are filled up as directed for them.

"The differences of latitude and the departures in the column of remarks entered against the last Station in each series, are computed from Table (C) in the Appendix, and serve to determine the relative geographical position of those Stations with reference to the first, or to any other Station in the series. The positions of places in maps are determined by similar entries, and are set off by scales of minutes and seconds from meridians upon parallels of latitude, in the same manner as the Stations in the adjoining diagram were by scale of miles and parts. Thus, if it were required to lay down the position of Duriapoor in a map of India, the latitude and longitude of Hatras, the first Station in the survey being known, it would be done in the following manner:—

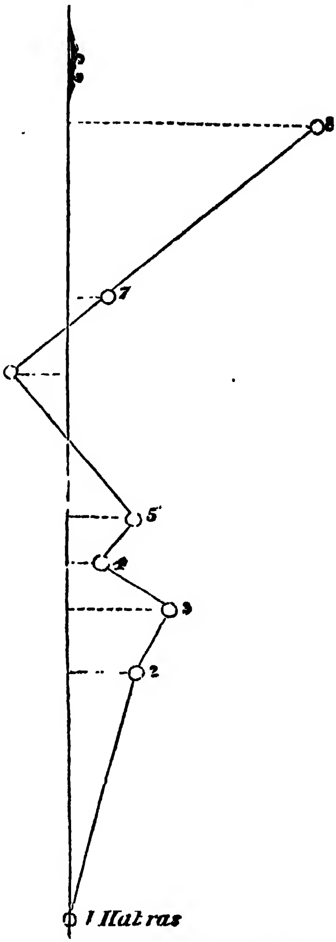
HATRAS,	...	Lat.	N. 27°	36′	00″		Long.	E.	78°	04′	00″
Duriapoor,	... diff.	Lat.	N.	2	49·4	diff.	Long.	E.		04	01·08
Duriapoor,	true	Lat.	N. 27	38	49·4	true	Long.	E.	78°	08	01·08

"With the true latitude and longitude so found, the position of the village would be fixed by the intersection of co-ordinates from the nearest meridian and parallel of latitude on the map and the position of any other point or place in the survey would be laid down in a similar manner."

Traverses of a Part of the Road between Hatras and Bareilly. Surveyed March, 1836, by CAPTAIN J. T. BOILEAU, *Bengal Engineers.*

Station.	Names of Places.	True Bearing by Theodolite.		Distances Measured.			Traverses of each Distance. Latitude. North.			South.			Departure. East.			West.			Traverses of each Station reduced to first Station. N. or S.	Latitude.			Departure.			E. or W.	REMARKS.
		°	′	M	F	Links.	M	F	Links.	M	F	Links.	M	F	Links.	M	F	Links.		M	F	Links.	M	F	Links.		
1	Hatras ⊙ of Bazar ..	14	00	..	1	350	..	1	309·3	..	..	..	..	..	328·9	..	..	....	N	..	..	....	..	..	....	..	This is also Sta. 1, Lieut. Hill's survey.
2	Ditto E. Gateway ..	31	..	..	..	382	..	..	327·4	..	..	..	..	..	196·7	..	..	....	N	..	1	309·3	..	..	328·9	E	
3	.. .. ..	315	42	..	..	450	..	..	262·6	..	..	..	..	..	..	..	..	365.4	N	..	1	636·7	..	..	525·6	E	The Lat. of Sta. 1, 27° 36′ N. By observation.
4	.. .. ..	37	15	..	..	314	..	..	249·9	..	..	..	..	..	190·1	..		....	N	..	1	899·3	..	..	160·2	E	
5	Kure ka nugra ..	319	30	..	1	..		..	760·4	..	..	..	..	..	..	..	..	649·4	N	..	2	149·2	..	..	350·3	E	
6	Jerma nugra ..	52	..	..	..	636	..	..	391·6	..	..	..	..	..	501	..	..	....	N	..	2	909·6	..	..	299·1	W	The Longitude of Sta. 1, 78° 04′ E. By account.
7	.. .. ..	49	..	..	..	427	..	..	936·2	..	..	..	..	1	076	..	..	....	N	..	3	301·2	..	..	201·9	E	
8	Kundharee-kee Gurhee ..	63	30	..	1	295		..	577·8	..	..	..	..	1	158·9	..	..	....	N	..	4	237·4	..	1	277·9	E	
9	.. .. ..	66	..	..	1	741	..	..	708·1	..	..	..	..	1	590·4	..	..	....	N	..	4	815·2	..	2	436·8	E	
10	Jogeepoor ..	41	06	..	2	609	..	1	589·3	..	..	..	..	..	386·4	..	..	....	N	..	5	523·3	..	4	027·2	E	
11	.. .. ..	54	20	..	4	741	..	2	764·3	..	..	..	..	3	851·7	..	..	....	N	..	7	112·6	..	5	413·6	E	
12	Sokna begins ..	56	10	..	..	573	..	..	319	..	..	..	..	..	476	..	..	....	N	1	1	876·9	1	1	265·3	E	
13	Ditto ends ..	73	30	..	..	818	..	..	230·7	..	..	..	..	..	785	..	..	....	N	1	2	195·9	1	1	741·3	E	
14	Rutungurhee ..	58	30	..	6	714	..	3	508·1	..	..	..	..	5	724·7	..	..	....	N	1	2	426·6	1	2	526·3	E	
15	Ditto ..	56	..	..	..	727	..	..	406·5	..	..	..	..	..	602·7	..	..	....	N	1	5	934·7	2	0	251	E	
16	.. .. ..	49	30	..	2	591	..	1	682·7	..	..	..	..	1	970·2	..	..	....	N	1	6	341·2	2	0	853·7	E	
17	.. .. ..	[illegible]	..	..	..	682	..	..	400·8	..	..	..	..	..	551·7	..	..	....	N	2	0	023·9	2	2	823·9	E	
18	.. .. ..	58	..	..	3	695	..	1	958	..	..	..	..	3	133·5	..	..	....	N	2	0	424·7	2	3	375·6	E	
19	.. .. ..	54	..	..	1	636	..	..	961·6	..	..	..	..	1	323·6	..	..	....	N	2	2	382·7	2	6	509·1	E	
20	.. .. ..	53	45	..	5	609	..	3	316·6	..	..	..	..	4	523·3	..	..	....	N	2	3	344·3	2	7	832·7	E	
21	Ujeetpoor ..	50	..	..	1	568	..	1	007·9	..	..	..	..	1	201·2	..	..	....	N	2	6	660·9	3	4	356	E	
22	Duriapoor ..	55	45	..	4	..	..	2	251	..	..	..	..	3	306·4	..	..	....	N	2	7	668·8	3	5	557·2	E	Diff. Lat 02′ 49·40″ N. ,, Long. 04′01·08′ E.
	Total ..	..	..	..	..	..	3	1	919·8	..	..	..	4	1	878·4	..	1	014·8	N	3	1	919·8	4	0	8603·2	E	

For the purpose of finding the equivalent values of latitude and longitude *in arc*, *i.e.*, in degrees, minutes and seconds, from the Tabular traverses expressed in units of linear measure, Table (C) in the Appendix is given, and the following remarks, to exemplify the process in performing this reduction, and the principles on which such reductions depend, are likewise borrowed from the same author:



"In the explanation of the adaptation of Traverse Tables to surveying, the surface of the earth within the limits of each set of operations has been considered as a plane, and the meridians as parallel straight lines; the relative lengths of the distance, difference of latitude, and departure, have been stated, not only to be accurately expressed by the three sides of a right-angled plane triangle, but to be truly projected by the construction of that triangle upon the map; both of these statements are, conformably with the hypothesis, strictly true, and boundary surveys, or indeed maps of small extent, may be projected with sufficient accuracy for all practical purposes by the rules given in the text. In route surveys, also where the general line lies near to a meridian or parallel of latitude, the results so obtained approximate very nearly to the truth; but where a considerable extent of country has to be mapped, or where the general line of a survey traversing the meridians at an oblique angle has to be represented, we are compelled to abandon our hypothesis,—the convergence of the meridians being sensible in extensive maps on any part of the earth's surface, but in a much greater degree in the higher latitudes than near to the equator: therefore, while we may still consider each individual Station to be correctly projected by the intersection of co-ordinates from the nearest meridian and parallel of latitude on a map, if we only take the necessary precaution in the field of correcting our bearings, whether true or magnetic, by observation, as often as the inclination of the meridians become sufficient to require it to be done,—still, a correction will be necessary to convert the departure between any two distant Stations, as obtained by the Traverse Tables, into the equivalent difference of longitude *in arc* between the same places. A similar correction would be necessary in the Tabular differences of latitude, but that the variation in the length of those degrees of latitude, lying near to each other, is so small as to be incapable of representation, excepting in maps of very large scale, and extending over great portions of the earth's surface.

"To obtain the difference of latitude and the departure for any bearing and distance, with perfect accuracy, by the Traverse Tables, it is essential that the distance should be an oblique rhomb line; *i. e.*, a portion of a spiral, cutting all the meridians over which it passes at the same angle; but where the lines are so short, as in a survey is generally the case, the difference between the lengths of a straight line, a circular arc, or a rhomb line,

drawn between any two Stations, is inappreciable, and we may therefore consider our Station lines as so many rhomb lines; and, consequently, the difference of latitude and the departures between any two distant places, as deduced from the intermediate lines in a survey, to be the same as if it had been obtained from a rhomb distance measured between those places.

"The departure and difference of longitude have, in the rules given for applying the Traverse Tables, been considered as identical; and this also, conformably with the hypothesis above mentioned, is strictly the case. The meridians are not, however, really parallel, though within short distances they may be so considered in practice, but converge towards the poles (Note page 257);* and the degrees of longitude, instead of being equal as they are assumed to be in the theory of the parallelism of the meridians, decrease in the same direction; therefore the departure and difference of longitude cannot any longer be considered as identical; for an equal amount of departure, *i.e.*, the same number of linear units, will measure different arcs of longitude according to the distance from the equator at which the departure may be reckoned. Thus, at the equator, a departure equal to 6086 feet, measures one minute of longitude, whereas at 89° it measures nearly a degree and proportionally at all intermediate stages. In measuring an oblique distance, therefore, it is evident that, supposing the distance to be divided into a number of infinitely small parts or increments, the amount of departure due to each increment ought to be reckoned in arc of longitude at its own distance from the equator, and that the departure for the whole distance when converted into longitude, will equal the sums of all the elementary arcs of longitude, of each increment in the distance. On moving from the equator towards the poles, these elementary arcs will be continually decreasing, and the contrary in travelling from the poles towards the equator, but there will be a certain point between the two extremities of each distance, or a certain *mean parallel of latitude*, upon which, if the *whole* departure be reckoned, it will express the true difference of longitude between the two extremities of that distance. This mean parallel is always higher than the *middle* parallel between those extremes, but in the construction of maps, where the measured distances are short, and the intervals between which the reduction of departure into longitude takes place are small, it will give results sufficiently near to the truth if we reckon the departure upon the *middle* parallel between the two extreme points of any distance.

"If the figure of the earth were truly spherical, all degrees of latitude would be equal, while the degrees of longitude would decrease in the direct ratio of the cosine of the distance from the equator; but, owing to the spheroidal figure of the earth, the degrees of latitude are not equal, but increase from the equator to the poles, the degrees of longitude decreasing in that direction in a ratio slightly different from that mentioned above. The greatest difference between any two successive degrees of latitude, which occurs about 45° from the equator, is 63 feet, or 1·05 feet in one minute, being rather less than 11 inches in one mile. This difference decreases both towards the equator and poles, and is too small to require the attention of the practical man, unless when his operations extend over a surface of many degrees: but in longitude the difference increases from 56 feet between the equatorial and first degrees, to 6393 feet at the poles; and, therefore, though not very sensible at first, it soon becomes so, even through the minutes and seconds of each degree.

"I shall now show the use and application of Table (C) in the reduction of Traverses, taking as examples the reductions entered in the column of remarks in the Table at page 337.

"*Example.* Required the difference of latitude and of longitude *in arc* between Hatras and Duriapoor, and the true latitude and longitude of the latter place, the Tabular traverses being N. 3 M. 1 Fur. 919·8 Lks., and 4 M. 0 Fur. 863·6 Lks. E; the latitude of Hatras being N. 27° 36′, and its longitude 78° 04′E.

* Boileau's Traverse Tables.

"Reduce the Tabular traverses to feet: divide the Tabular difference of latitude so reduced by the value of one minute or second of latitude in a line with the number corresponding nearest to the latitude of the starting point, in the column designated "distance from the equator;" and the quotient will be the difference of latitude required *in arc*. Add to, or subtract, this difference from the latitude of the starting point, according as it may be of the same or of a different denomination, and it will give the true latitude of the place required. Take the middle latitude between the starting point and that for which the difference of longitude is required, and correct the value of one minute or second in the Table, for the number in the column designated "distance from equator," corresponding nearest to that of the middle latitude. Divide the Tabular difference of longitude reduced to feet by the corrected value of one minute or second, and the quotient will give the difference of longitude *in arc* required; which being added to, or subtracted from, the longitude (from Greenwich) of the starting point as above, will give the true longitude of the place required.

	Feet.
Three miles ....=	15840
One furlong ....=	660
919 links (Table D) ....=	606·54
·8 ditto, (ditto) ....=	·528
Reduced diff. lat. N.	17107·068

	Feet.
Four miles ....=	21120
863 links (Table D) ....=	569·58
·6 ditto, (ditto) ....=	·396
Reduced diff. long.	21689·976 E.

Lat. of Hatras N. 27° 36′; value of 1′ of lat. for 28°, in Table C = 6059·1 and 17107·068 ÷ 6059·1 gives 02″·8233′, or N. 02′ 49″·40, nearly, for the diff. of latitude *in arc*, which added to the latitude of the starting point (being of the same denomination) gives N. 27° 36′ + N. 02′ 49″·40, or N. 27° 38′ 49·″40 for the true latitude of Duriapoor.

" Again for the difference of longitude in arc:

Latitude of Hatras ....N.	27°36′
Half diff. of Lat. of Duriapoor......... ....N.	01·41167
Middle latitude...........................N.	27°37·41167

Value of 1′ of longitude for 27°, Table C.........	5426·2
Ditto ....for 28°, ditto	5377·3
Difference for 1°	—48·9

Now 1°, or 60′ : 48·9 feet : : 37″·41167 : 30·49, and 5426·2—30·49 = 5395·71 feet, value 1′ of longitude to middle latitude: then, using this number as a divisor, we shall have the tabular difference of longitude reduced to feet 21689·976 ÷ 5395·71 = 4′·018′, or 04′01″·08E., the difference of longitude *in arc*, which added (as above) to the longitude (east of Greenwich) of Hatras (78° 04″) gives 78° 08′ 01″·08 E. for the true longitude of Duriapoor."

The latitude should be found by celestial observation at least once in twenty-four hours, and if the meridian altitude of the sun be within range of the instrument it should not be neglected, but the true observation to trust to, is the latitude by night from Stars north and south, which in a fine climate can nearly always be obtained, and the difficulty of measuring the altitude in low latitudes, when the double angle is larger than a sextant can measure, avoided. A sextant of five or eight inches radius and an artificial horizon, are the only safe instruments,

but these, of course, are useless for the meridional altitudes of the sun in low latitudes.

The determination of the longitude of a place requires more knowledge than is requisite to find its latitude. No pains should be spared, nor any time be considered misspent in endeavouring to fix accurately the chief points in a country by independent observations for longitude. The only trustworthy method for a locomotive observer is by occultations. One good observation of an occultation is worth fifty observations depending on the moon's motion; lunar distances are not to be relied on within 20 miles. Moon culminating stars, which is a favorite method, requires a long series of observations, and the fixing of the transit instrument takes several days, and the method depending on the moon's motion, the error is magnified twenty-eight times in the result. Eclipses of Jupiter's Satellites are unsatisfactory on account of the Penumbra. Unfortunately occultations occur very seldom and give a great deal of trouble, but the observation when made is very valuable and ought to be good within 2,000 or 3,000 feet at the outside, so that a couple of occultations is sufficient for a good approximation. It is also advisable that corresponding observations at an observatory should, if possible, be made. Chronometers are not to be trusted for long circuitous journeys, especially in a meridional direction.

The above methods, which are fully treated of in Part V, will enable the observer to fix the longitude of a place *absolutely*, that is to say, independently of the transport of time by a watch or chronometer, but for short distances this instrument will be perfectly serviceable, and connect one place with another, so that all may be *relatively* right in a map of the country, though *absolutely* wrong; and when at any subsequent opportunity the longitude of any one point may be correctly determined, all will move together in its right place.

"With regard to the management of a chronometer, the great point is to find its *error* at any place, the longitude of which is known, and its *rate* whenever an opportunity is afforded, by stopping two or three days in any place, and to make allowance for any alteration in rate over the whole route travelled since its rate was last determined.

"The mode of finding the longitude before described, by keeping an exact itinerary of the courses by the compass and the distance travelled, corrected for variation, and checked by observations for latitude, is the simplest, and will give a very fair approximation, and this method should never be neglected, as it will serve as a useful check to astronomical observations.

"By these means a careful and industrious traveller can hardly fail of obtaining abundant materials for the correct laying down of his route, and should he traverse the country in different directions, he will thus have a number of lines crossing each other forming a route map, from which, for want of a regular survey, a very fair idea of the country may be gleaned, particularly when such map is accompanied by a detailed description. Another essential object to which we would call the traveller's attention is, never to go to sleep until he has mapped his day's route, and written up his journal from the notes of the day."*

To show the accuracy with which this description of survey may be carried out, we subjoin an account of the Ray Trace System as pursued in the Great Trigonometrical Survey, and detailed in the following Chapter.

NOTE.—The following works and papers afford much valuable information connected with the subject of this Chapter, and may be referred to with advantage.

"Manual of Field Fortification, Military Sketching and Reconnaissance." Published in 1871 by authority from the Horse Guards, for the instruction of Officers in the Army, and ordered by H.R.H. the Field Marshall, Commander-in-Chief, to be followed at all Military Educational Establishments.

"Out-post Duty and Treatise on Military Reconnaissance and Road-making." By Major-General W. C. E. Napier, 1869.

"A Practical Course of Military Surveying, including the Principles of Topographical Drawing." By Captain Lendy, F.G.S. F.L.S., &c., 1864.

"Practical Military Surveying and Sketching," &c. By Major Drayson, R.A., 1869.

"Notes on Maps." By Captain C. W. Wilson, R.E., Director, Topographical Department, of the War Office; published in Lectures addressed to Officers of Volunteer Corps at the Royal United Service Institution, 1873.

* "What to Observe; or, The Traveller's Remembrancer." By J. R. Jackson.

CHAPTER II.

The Ray Trace System of the Great Trigonometrical Survey.

Analogous to the route survey, is the Ray Tracing System, introduced by Lieutenant-Colonel Everest, formerly Surveyor General of India, and described at page 19 of his account of the "Measurement of two Sections of the Meridional Arc of India," published in 1847. This is most useful, where it is necessary to know the exact line between two places for road-making, or the proper direction in which to lay the telescope for observing the Blue Light Signals, which are burned by sets of four, at ten minutes interval between each lighting, and which are scarcely in a single instance, during the whole of the operations of the Great Trigonometrical Survey, visible to the naked eye. Without calculating this direction beforehand, it would be impossible to say, in the side of a triangle, perhaps 10 to 15 miles, how the ray would fall, and which identical trees would require to be felled. For this purpose a minor series of traingles, or a simple route, is carried on along the ray, commencing from the station of the eye and terminating at that of the object, wherein, by assuming the most commodious of the first two sides as unity, and as the line of direct co-ordinates, it is easy to compute not only the angle which the ray makes with this line, but also the ratio which they bear to each other.

The following directions, computation and example of a Ray Trace, have been drawn up in conformity with these principles, and are precisely those at present employed in the Great Trigonometrical Survey of India. Most of the rays for the principal triangles have been worked out in this manner, whence the method, whether executed by minor triangulation, or perambulator measurement, has derived the name of "Ray Tracing," and affords ample opportunities for filling in topographical details, and fixing the secondary points, within large triangles.

Every Route Survey, conducted on the principles of the Ray Trace, should, if possible, originate in a point previously determined by a Trigonometrical Survey; when a fixed point of this kind is not available, the origin of the route should be placed on some permanent object, such as a mosque, a temple, a church or a masonry building, &c., the position of which can be readily ascertained whenever required, by a trigonometrical operation.

In a Route Survey, the measurements required consist of two parts, viz., linear and angular. The measurements of the former kind are usually made with a perambulator, and those of the latter are invariably executed with a theodolite; the angular measurements are much less liable to error than the linear measurements; whence the corrections arising from all and every discrepancy exhibited by a Route Survey, are exclusively applied to the measured distances, thereby leaving unaltered the observed angles which are considered errorless; on this assumption is based the common method for computing and reducing a Route Survey.

After the origin of the survey has been determined upon, the Surveyor proceeds forward and selects stations in the route; the conditions to be attended to in this operation are, 1st, the reciprocal visibility of the adjacent stations, and 2nd, the eligibility of the intermediate ground for a perambulator measurement.

In closing the operation, it must terminate also on a point which has been either determined trigonometrically, or which is capable of being so determined in future.

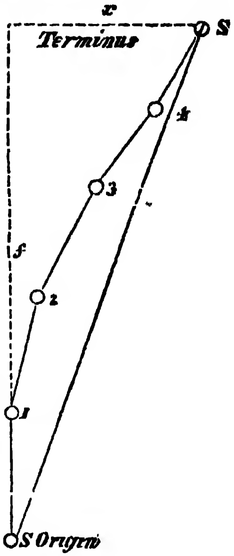
When the origin and terminus of a Route Survey are fixed points, any error committed in the execution of the work is susceptible of easy elimination as will afterwards appear.

After the Stations are selected, the next thing is the measurement of the distances and angles. For this purpose, a reading of the perambulator at the origin is taken, and then it is rolled forward in a straight line to ⊙ 1, where a second reading is taken; here likewise the theodolite is adjusted, and the angle between the origin and ⊙ 2 observed; this observation should be repeated on both faces of the instrument; the advantages attending the taking of this double observation are these:— In the first place the record is checked, and secondly, any error induced in the individual observations by the unadjusted line of collimation, or the dislevelled transit axis, disappears in the mean value thereof.

After ⊙ 1 is disposed of, the Surveyor proceeds to ⊙ 2, where he takes observations similar to those made at ⊙ 1; the remaining stations of the route being treated in like manner, he will at last arrive at the terminus, where having no angle to observe, he will only note down the reading of the perambulator; after the completion of the field measurement, the computation of the route is made, the principles and method of executing which may be explained in the following manner:—

On reference to the diagram in the margin, it will be perceived that if the first line (origin to ⊙ 1) be extended so as to meet the perpendicular drawn thereto from the terminus, the lengths of these two lines being

known, all the other elements of the route are ascertained by a very easy computation.



For instance, calling y the perpendicular above mentioned, and x the line drawn from the origin to meet it, $\frac{y}{x} = \tan \theta$, θ being the angle at the origin between $\odot$ 1 and the terminus.

Again, the whole distance from the origin to the terminus of the route is equivalent to $\rho = x . \sec \theta$.

The use of these elements for correcting the measured distances of the route, and for laying off the direct line from the origin to the terminus, will be shown presently.

In the computation of a Ray Trace Survey, it should be premised that x is taken as the axis of the direct, and y that of the perpendicular co-ordinates.

Besides x and y, there are other symbols required to designate the measured distances and angles, and the characters usually made use of for this purpose are as follows:

Distance Origin to $\odot$ 1 $= a$
Ditto $\odot$ 1 to $\odot$ 2 $= a$
Ditto $\odot$ 2 to $\odot$ 3 $= b$
Ditto $\odot$ 3 to $\odot$ 4 $= c$

Again,

Mean observed angle at $\odot$ 1 $=$ $\odot$ 1
" " Ditto at $\odot$ 2 $=$ $\odot$ 2
" " Ditto at $\odot$ 3 $=$ $\odot$ 3

These observed angles are deduced by subtracting the reading of the rear station from that of the forward point, and consequently they may be of any value whatever from 0° to 360°.

From the observed angles deduced as directed above, let the following arcs called angles for computation be computed.

$$A = \odot 1$$
$$B = A + \odot 2 - \pi$$
$$C = B + \odot 3 - \pi$$
$$D = C + \odot 4 - \pi$$

That is to say, the angle for computation at any station is equivalent to the observed angle, augmented by the last angle for computation, and diminished by 180°;* the angles for computation, as deduced above, are those at which the lines a, b, c, ... are inclined to the first line a, or to the parallels thereof.

After the deduction of the angles for computation, it is necessary to calculate the following terms:

$$x' = a.\cos A \qquad y' = a.\sin A$$
$$x'' = b.\cos B \qquad y'' = b.\sin B$$
$$x''' = c.\cos C \qquad y''' = c.\sin C$$

x', x'', x''' .... are called direct co-ordinates, they being the projections of a, b, c, ... on the axis x; similarly y', y'', y''' .... being the projections of the same lines on the axis y, are called perpendicular co-ordinates; the signs of these co-ordinates depend upon the magnitude of the angles from which they are respectively derived, and these signs will be readily found by a reference to the following table:

Table exhibiting the Signs of the direct and Perpendicular Co-ordinates.

Magnitude of the angles for computation.	Signs of the Co-ordinates.	
	Direct.	Perpendicular.
Quadrants.		
1st.	—	—
2nd.	+	—
3rd.	+	+
4th.	—	+

After affixing proper signs to the direct and perpendicular co-ordinates, collect the former into one sum and the latter into another; the former of these sums augmented by the first distance (a), is the numerical value of x, while the latter sum is the numerical value of y.

After the values of x and y are determined, θ and ρ may be deduced by the following formulæ:

$$\operatorname{Tan}\theta = \frac{y}{x}; \qquad \rho = x.\sec\theta.$$

* The established symbol for a semicircle or 180° is π

Now $\angle\ \theta$ is of the same sign with y, and may be either positive or negative. In the former case, the terminus is to the right, and in the latter to the left, of ⊙ 1; knowing the value of θ, as likewise its position with respect to ⊙ 1, it is easy to trace the direct line of the route. For this purpose, put up the theodolite at the origin, and take a reading to ⊙ 1. To this reading apply, according to its sign, the $\angle\ \theta$; the resulting reading, or the telescope set thereto, will point to the terminus of the survey.

Again, if it be required to trace the route from the terminus, it may be done thus: According as θ is positive or negative, add it to, or subtract it, from π. From the sum or difference so obtained (augmented when less than the subtractor by 2π), deduct the last angle for computation, the remainder will be the $\angle\ \theta'$ at the terminus between the origin and the last station of the route. The $\angle\ \theta'$ may be of any value from 0° to 360°; it is likewise always positive. Adjust the theodolite over the terminus, and take a reading to the last station; to this reading add the $\angle\ \theta'$: the resulting reading will be the required direction of the origin from the terminus.

It is evident that ρ, determined as directed above, is in terms of the perambulator, calling R the value of the same distance as derived from a trigonometrical operation, it follows that $\rho \backsim$ R is the error of the Route Survey.

Without making any assumption as to the cause of this error, it is evident that this discrepancy must be expunged, before the details furnished by a Route Survey can incorporate with those of a trigonometrical operation.

The simplest and perhaps the only method of performing this, is by the following rule of proportion.

As the direct perambulator distance of the route (ρ)

: The trigonometrical value thereof (R)

:: Each measured perambulator distance

: Its corresponding trigonometrical length.

Correcting by this proportion all the perambulator distances, as well as all the co-ordinates deduced therefrom, the resulting elements will obviously be in terms of the unit of the Trigonometrical Survey.

The following is an example of the field notes and computation deduced therefrom:

SPECIMEN OF THE RAY TRACE SURVEY FIELD-BOOK.

TRACING OF RAY DONAO TO KAINKERA, 10TH AND 11TH NOVEMBER, 1842.

Route Survey by LIEUT. A. S. WAUGH, with 7-inch Theodolite B, No. 12, & Perambulator No. 2, with 6-mile Dial.

Station of Observation.	Objects Observed.	Face.	Vernier Readings. A	Vernier Readings. B	Vernier Readings. C	Vernier Readings. Mean.	Angles deduced. One Reading.	Angles deduced. Mean.	Perambulator. Readings Miles.	Perambulator. Distances.	Remarks.
Donao ...	....	...	....	......	......	....	....	....	1·964		
⊙ 1, near Manjilia ...	Mag. north, Donao, ... ⊙ 2 ...	L	° ′ ″ 0 0 314 11 0 132 24 0	′ ″ 10 30 23 30	′ ″ 10 30 23 45	° ′ ″ 314 10 40 132 23 45	° ′ ″ 178 13 5	° ′ ″ 178 13 40	3·039	1·075	
	Donao, ... ⊙ 2 ...	R ...	134 9 15 312 23 45	9 15 23 15	9 0 23 15	134 9 10 312 23 25	178 14 15.				
⊙ 2, near Bikaripur .	Mag. north, ⊙ 1 ... ⊙ 3 ...	L ... 	0 0 0 312 10 0 130 37 0	...... 9 15 36 45	...... 9 30 36 45	.... 312 9 35 130 36 50	.... 178 27 15	.... 178 27 23	6·251	3·212	
	⊙ 1 ... ⊙ 3 ...	R ...	132 8 45 310 36 45	9 0 36 0	9 0 36 30	132 8 55 310 36 25	178 27 30				
⊙ 3, near Simeria ...	Mag. north, ⊙ 2 ... ⊙ 4 ...	L	0 0 0 310 36 45 121 35 30	...... 35 30 35 30	...... 36 15 35 15	.... 310 36 10 121 35 25	.... 170 59 15	.... 170 58 49	1·432	1·181	
	⊙ 2 ... ⊙ 4 ...	R ...	130 41 45 301 40 15	41 45 39 50	41 30 40 0	130 41 40 301 40 2	170 58 22				

⊙ 4, between Piperia and Mangabpur.	Mag. north,	L	0 0 0	......	......	....	....	....	3·038	1·606	
	⊙ 3 ...	...	301 40 0	39 30	39 45	301 39 45	185 27 0	185 26 43			
	⊙ 5 ...	...	127 6 45	6 45	6 45	127 6 45					
	⊙ 3 ...	R	121 40 30	40 45	40 45	121 40 40	185 26 25				
	⊙ 5 ...	...	307 7 30	6 45	7 0	307 7 5					
⊙ 5, near Ratanpuri.	⊙ 6 ...	L	162 59 0	58 30	58 30	162 58 40	215 54 10	215 54 0	4·805	1·767	
	⊙ 4 ...	...	307 5 0	4 0	4 30	307 4 30					
	⊙ 4 ...	R	127 8 15	8 15	8 0	127 8 10	215 53 50				
	⊙ 6 ...	...	343 2 15	1 45	2 0	343 2 0					
⊙ 6, near Jondapur...	⊙ 5 ...	L	342 59 45	59 15	59 45	342 59 35	184 0 0	184 0 5	5·700	0·895	
	⊙ 7 ...	...	166 59 45	59 30	59 30	166 59 35					
	⊙ 5 ...	R	162 58 30	58 30	58 30	162 58 30	184 0 10				
	⊙ 7 ...	...	346 59 0	58 30	58 30	346 58 40	....	....	...	...	Measurement given up at ⊙ 6 on the evening of the 10th.
⊙ 6, near Jondapur...	....	...	....	......	......	....	....	....	2·245	...	Measurement resumed at ⊙ 6 on the morning of the 11th.
⊙ 7, near Mohanpur.	⊙ 6 ...	L	347 7 0	6 30	6 45	347 6 45	155 22 0	155 22 13	2·952	0·707	
	⊙ 8 ...	...	142 29 0	28 45	28 30	142 28 45					
	⊙ 6 ...	R	167 0 30	1 0	0 30	167 0 40	155 22 25				
	⊙ 8 ...	...	322 23 30	22 45	23 0	322 23 5					
⊙ 8, or Kainkera Station.	....	...	....	......	......	....	....	....	4·074	1·122	

TYPE OF CALCULATION OF RAY, DONAO TO KAINKERA.

Distances.	Miles.	
Donao to ⊙ 1	= 1·075	= a
⊙ 1 to ⊙ 2	= 3·212	= a
⊙ 2 to ⊙ 3	= 1·181	= b
⊙ 3 to ⊙ 4	= 1·606	= c
⊙ 4 to ⊙ 5	= 1·767	= d
⊙ 5 to ⊙ 6	= 0·895	= e
⊙ 6 to ⊙ 7	= 0·707	= f
⊙ 7 to Kainkera	= 1·122	= g

Observed Angles.	°	′	″
At ⊙ 1 =	178	13	40
⊙ 2 =	178	27	23
⊙ 3 =	170	58	49
⊙ 4 =	185	26	43
⊙ 5 =	215	54	0
⊙ 6 =	184	0	5
⊙ 7 =	155	22	13

Hence the Angles for Computation are—

$$
\begin{aligned}
A &= 178^\circ\ 13'\ 40''\\
B &= (178\ 13\ 40 + 178^\circ\ 27'\ 23'' - \pi) = 176^\circ\ 41'\ \ 3''\\
C &= (176\ 41\ \ 3 + 170\ 58\ 49 - \pi) = 167\ 39\ 52\\
D &= (167\ 39\ 52 + 185\ 26\ 43 - \pi) = 173\ \ 6\ 35\\
E &= (173\ \ 6\ 35 + 215\ 54\ \ 0 - \pi) = 209\ \ 0\ 35\\
F &= (209\ \ 0\ 35 + 184\ \ 0\ \ 5 - \pi) = 213\ \ 0\ 40\\
G &= (213\ \ 0\ 40 + 155\ 22\ 13 - \pi) = 188\ 22\ 53
\end{aligned}
$$

A=178° 13′ 40″	Cos. 9·99979		Sin. 8·49033		
a=3·212	Log. 0·50678		Log. 0·50678		
	0·50657	... + 3·210	$\bar{2}$·99711	...—0·099	
B=176 41 3	Cos. 9·99927		Sin. 8·76223		
b,=1·181	Log. 0·07225		Log. 0·07225		
	0·07152	... + 1·179	$\bar{2}$·83448	...—0·068	
C=167 39 52	Cos. 9·98986		Sin. 9·32968		
c =1·606	Log. 0·20575		Log. 0·20575		
	0·19561	... + 1·569	$\bar{1}$·53543	...—0·343	
D=173 6 35	Cos. 9·99685		Sin. 9·07907		
d=1·767	Log. 0·24724		Log. 0·24724		
	0·24409	... + 1·754	$\bar{1}$·32631	...—0·212	

E=209° 0′ 35″	Cos. 9·94178		Sin. 9·68570	
e =0·895	Log. $\bar{1}$·95182		Log. $\bar{1}$·95182	
	$\bar{1}$·89360	... +0·783	$\bar{1}$.63752	... +0·434
F=213 0 40	Cos. 9·92354		Sin. 9·73624	
f =0·707	Log. $\bar{1}$·84942		Log. $\bar{1}$·84942	
	$\bar{1}$·77296	... +0·593	$\bar{1}$·58566	... +0·385
G=188 22 53	Cos. 9·99534		Sin. 9·16364	
g=1·122	Log. 0·04999		Log. 0·04999	
	0·04533	... +1·110	$\bar{1}$·21363	... +0·164
a =		... +1·075		

Sum of Direct Co-ordinates .... x = +11·273 Sum of Perpendicular Co-ordinates y = +0·261

Sum of Direct Co-ordinates x=11·273	Log. 1·05204	
	A. C: 8·94796	
Sum of Perpr. Co-ordinates y= 0·261	Log. $\bar{1}$·41664	
θ = +1° 19′ 35″	Tan. 8·36460	Cos. 9·99988
		Sec. 0·00012
Sum of Direct Co-ordinates x=11·273	....	Log. 1·05204
Distance by Perambr. measurement	....	Log. 1·05216
Ditto by Triangulation	.. ..	Log. 1·04716
Constant Log. of Correction	....	Log. $\bar{1}$·99500

This constant logarithm added to the logarithms of the perambulator distances will furnish the logarithms of the same distances in terms of the unit of the Trigonometrical Survey.

θ′ Computed.

		°	′	″
	$\pi + \theta$ =	181	19	35
Which being less than subtractor, is augmented by 2 π, and becomes	=	541	19	35
Deduct G or last ∠ for computation......	=	188	22	53
Hence	θ' =	352	56	42

The following is the method of computing a Ray Trace Survey without the aid of the trigonometrical distance, wherewith it is connected.

The method just explained for the computation of a Route Survey, requires a previous knowledge of the distance of S to S′; but it sometimes happens in practice that this information is not forthcoming and cannot be ascertained without a tedious computation, in which case, the following method of deduction should be adopted, which determines the true positions of the Route Survey points, without reference to the direct distance between the two trigonometrical Stations, wherewith they are connected.

In the diagram (page 457) S and S′ are two trigonometrical Stations, and ⊙ 1, ⊙ 2, ⊙ 3 are points of a Route Survey, which originates in S and terminates at S′.

The elements supposed to be given are the latitude and longitude of S and also the azimuth of ⊙ 1 from S.

With the perambulator distance S to 1, and the elements above given, deduce the latitude and longitude of ⊙ 1, as also the back azimuth of S; with the back azimuth of S and the observed angle at ⊙ 1, compute the forward azimuth of ⊙ 2 from ⊙ 1; with this azimuth again, and the given perambulator distance ⊙ 1 to ⊙ 2, deduce the latitude and longitude of ⊙ 2; by a similar process, the latitudes and longitudes of the other points of the Route Survey, as likewise of trigonometrical Station S′ may be derived.

When the computation arrives at S′, the deduced latitude and longitude of this Station will probably differ from the respective trigonometrical values; the discrepancies thus displayed present, under an accumulated form, the whole error of the survey. To eliminate this error, add all the perambulator distances together, and take the logarithm of the sum; to the arithmetical complement of this logarithm, add the log. of the error in latitude, the sum will be a constant log.; to this constant log., add separately and in the order in which they stand, the logs. of the several perambulator distances of the survey, and find the natural numbers corresponding to these sums: now the correction for the first Route Survey point is the first natural number; the correction for the second point is the sum of the first and second natural numbers; similarly the correction for the third Route Survey point is the sum of the first three natural numbers; and in the same manner, the correction for the other points, and also that for trigonometrical Station S′ may be deduced.

It is evident, that the deduced correction for S′ ought to be identical with the whole error exhibited by the survey, and when this takes place, the computation of the corrections may be assumed as having been correctly performed; in this computation the logs. used should be carried to five decimals, and the natural numbers deduced should be limited to a tenth of a second.

The error in longitude may be corrected in the same way as that in latitude; this mode of dispersing the error of a Route Survey is likewise applicable when the positions of S and S' have been fixed by astronomical observation.

The method of carrying out the Ray Trace System by minor triangulation will be treated of in a subsequent Chapter.

CHAPTER III:

TRIGONOMETRICAL SURVEYING, AND THE MODE OF OPERATIONS TO BE PURSUED IN HILLY COUNTRIES.

IN the system of survey which has been described in the last few chapters of Part III, shewing the style of a Revenue Survey, which embraces all villages situated in a champaign or well cultivated country, the relative positions of the several Stations are ascertained by direct *linear-measurement;* but in a less favored, or mountainous and densely-wooded country, where, on account of the inequalities of surface, the measurements are liable to more than ordinary errors, and to connect the measurement of one village with another, with any degree of expedition, is almost rendered impossible, it is necessary, in order to prevent accumulation of errors, that the detail measurements be based on an accurate system of triangulation.

To pursue a Topographical Survey of countries of the above description, which latterly have been met with to a considerable extent in the course of the Revenue Operations in India, a Trigonometrical Basis becomes essential; we therefore propose to enter into such details for the prosecution of a Trigonometrical Survey, founded on the principles and system as are now actually in use, as will enable the Surveyor to prepare himself for every emergency; for all surveys executed without due regard to this precaution, however carefully the details may be performed, partake of the character of detached operations which are incapable of union *inter se,* or of harmonious combination with other surveys.

Base Line.

All Trigonometrical Operations emanate either from some actually measured line, called a *Base Line,* or from a side of some other Trigonometrical Survey, the length of which is known by calculation. As a general rule, for all surveys of a secondary order, the measurement of a base should never be attempted, if by any possibility the side of a triangle of the Great Trigonometrical Survey can be obtained, and it will be found preferable to go a little out of the way to secure this, and to perform a little extra triangulation, in consequence, than to spend time on so difficult and tedious a task as the measurement of a base with rude and imperfect instruments, the results of which will never equal the value of a computed side, deduced with the scrupulous care and nicety of an important Trigonometrical Survey.

The measurement of a Base Line, from which the sides of the triangles of an extensive series are to be calculated, such as for the measurement of an arc of the meridian, although apparently easy, is the most difficult and important part of a Trigonometrical Survey, as upon its accuracy that of every triangle depends, and one in which every refinement, which mechanical ingenuity can devise, has been adopted, with a view to obtain mathematical accuracy. The length of the base is made to depend in general on the proposed length of the sides of the triangles, which are to be deduced from it, but circumstances seldom allow it to exceed from seven to eight miles in extent, as its position is to be selected on an even plain, as nearly as possible horizontal, and otherwise conveniently adopted for purpose of measurement, where both ends of the base would be visible from each other, as well as from such Stations with which they should form symmetrical triangles.

Our limits will not admit of entering into a description of the different implements, which have at divers times been made use of for the measurement of a Base Line. Formerly, in the English, as well as in the Indian, Trigonometrical Survey, steel chains of one hundred feet in length were employed in this operation, but this implement has now been set aside, and the apparatus introduced in its place are the compensation bars and microscopes. On the Continent, rods of different metals, as platina, copper, iron, &c., are used in measuring a Base Line.

When a Base Line is measured with a metallic rod or chain, it will stand in need of a correction dependant upon temperature, because the length of the measuring implement varies with the indications of the thermometer. When the compensation bars and microscopes are employed, the correction for temperature is never required, that apparatus being so constructed, as to indicate the same, or nearly the same length, under every variation of temperature.

Full accounts of the measurement of the Base Line with compensation bars and microscopes, will be found in Everest's Account of the Measurement of the Arc of the Meridian, 1847, and in Yolland's Ordnance Survey, 1847. Again, Lambton's Papers in the Asiatic Researches, as likewise Everest's first work on the Indian Arc, published in 1830, contain accounts of Base Lines measured with a steel chain. But the paper which would be most serviceable to the Indian Surveyor is that published by Captain Herbert, in the 14th volume of the Asiatic Researches, in which he gives an account of the measurement of a temporary Base Line, executed with deal rods in the Dehra Dhoon, for the purpose of making a Trigonometrical Survey of part of the Himalayah Mountains.

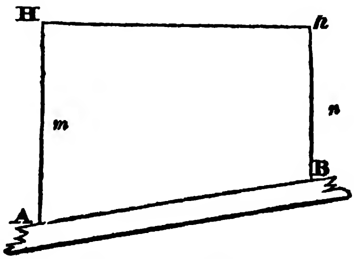
The method of laying out a Base Line previous to measurement is thus done. A *Boning* instrument,* or in lieu thereof a theodolite, being firmly planted at the origin, its line of collimation and the transit axis being likewise truly adjusted; marks are then fixed in the ground, at different distance, in a continuous vertical plane, as far as the power of the telescope will permit; the instrument is then taken forward to within three or four marks, or pickets of the extremity of the line ranged, and placed correctly over one of them by means of the plummet, and by the intersection of the crosswires of the telescope, directed to the back and forward pickets successively. This done, other marks are then fixed in the same vertical plane until the terminus of the Base Line is reached.

Boards, 12 or 15 inches square, with concentric black and white rings painted on both sides, make good ranging marks. Besides the marks at the extremities of a Base Line, which should always be constructed so as to be *permanent*, two or three intermediate points should be carefully determined and marked, during the progress of the measurement, so as to serve for testing the accuracy of the different portions, by comparing them with each other by minor triangulation.

In measuring a base for an ordinary Topographical or independent Survey of any moderately-sized portion of country, it will be sufficient to measure its length carefully two or three times with well seasoned fir or teak rods, or a good steel chain, which has been carefully compared with a standard.

The rod or chain employed in the operation should be always, if possible, adjusted to a horizontal position; but this is a condition which the unevenness of the ground would occasionally prevent being carried into effect. When this occurs, the angle, at which the measuring implement is inclined to the horizon, should be carefully observed and registered in the Base Line book.

As the theodolite is the only instrument which is likely to be at the disposal of the Revenue Surveyor, we will proceed to show how it may be employed in determining the angle above mentioned. The theodolite being fixed at a convenient spot in the alinement of the Base Line, adjust the telescope, or rather the line of vision thereof, to a horizontal position. Let H*h* represent this line. Also suppose



* The *Boning* Instrument is used only for Base Line operations; it has the common properties of the Theodolite, only with more perfect adjustments to the line of Collimation and of the Horizontal and Transit Axis Levels, and in addition *lateral* motion to the Telescope. This instrument is always used in the Base Line Measurements of the Great Trigonometrical Survey of India.

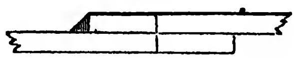
AB to be the measuring implement, placed, as will be required, in the course of the measurement. Now the lengths of the lines AH and Bh can easily be ascertained, by holding first at A, and then at B, a perpendicular staff, and marking thereon the points at which it is cut by the visual line of the telescope. Calling m the former and n the latter of these lines, it is evident, firstly, that when m and n are equal, the measuring implement is horizontal; and secondly, that when this equality does not obtain, the implement in question is inclined to the horizon, the advanced end B being higher or lower than the rear end A according as m is greater or less than n.

It is also clear that sin. $i = \frac{m \backsim n}{h}$, in which i denotes the inclination of the measuring implement to the horizon, h being its length.

When the measuring implement is laid inclined to the horizon, the distance it measures off on the latter plane is equivalent to its projection thereon. Putting $m \backsim n = d$ and $p =$ length of the projection abovementioned, we shall have $p = \sqrt{h^2 - d^2}$, which expanded becomes $h - \frac{d^2}{2h} - \frac{d^4}{8h^3} - \frac{d^6}{16h^5}$ Compute therefore the terms $\frac{d^2}{2h}$, $\frac{d^4}{8h^3}$, and subtract their sum from h, the remainder will be the value of the projection of the measuring implement on the plane of the horizon.

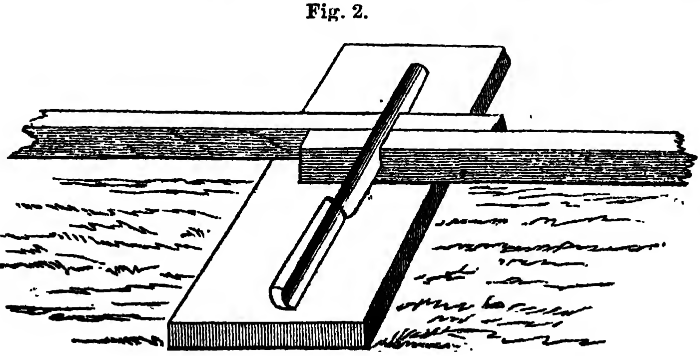
A good method is to lay the pair of rods, as it is termed "in coincidence," that is, lines drawn across them near their extremities, are made to coincide most accurately as in the sketch (Fig 1).

Fig. 1.



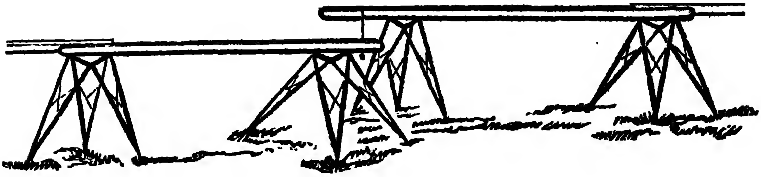
The ends of the rods may be laid together on tripod stands (Fig. 3),

Fig. 2.



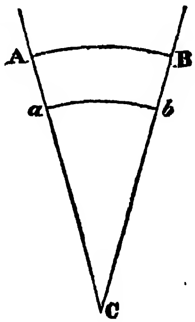
CHAPTER III.]

Fig. 3.



a set of six being properly allined and levelled, and where the inequalities of the ground render it necessary to alter the level, a plumb line is sufficient to obtain a coincidence of the marks on the rods. If the tripod stands are not available, boards may be laid down, the edge of a common table knife being placed along the divisions or cuts on the rods, to show the coincidence, as in Fig. 2.

In order to compare together, and connect bases measured at different elevations in distant parts of the country, it is necessary that they be referred to a common elevation. For this common standard, the mean level of the sea naturally presents itself as the most suitable, admitting, by its very nature and universal access, of easy reference.



A base measured on an elevated plain is thus reduced to its proper measure at the level of the sea.

Let r = radius of the earth (supposed to be spherical) at the the level of the sea. r + h = radius at the level of the measured base.

A = measured base AB

a = reduced base ab

Then because similar arcs are in the same ratio as their radii, we have,

$$r + h : r :: A : a$$

which gives $a = \dfrac{rA}{r+h} = A\left(1 + \dfrac{h}{r}\right)^{-1}$ which expanded by common division becomes

$$A\left\{1 - \frac{h}{r} + \frac{h^2}{r^2} - \frac{h^3}{r^3} + \&c. \ldots\right\}$$

Therefore $a = A - \dfrac{Ah}{r} + \dfrac{Ah^2}{r^2} - \dfrac{Ah^3}{r^3} + \&c. \ldots$

Subtracting both sides of the equation from A, there will arise

$$A - a = \frac{Ah}{r} - \frac{Ah^2}{r^2} + \frac{Ah^3}{r^3} - \&c.$$

which is the required expression for the reduction of the measured line to the level of the sea, and in which it will never be necessary to use more than the first term.

As an example to illustrate this formula, we will take the Base Line measured by Col. Lambton, in 1815, in the Valley of Beder—

		Feet.		
Measured length of the Base Line	$A =$	30809.07	Log.	4.48868
Mean height of the base above the sea level	$h =$	1957.	Log.	3.29159
Mean radius of the earth	$r =$	20888153.	Log. AC	$\bar{8}$.68010
Required correction		2.89		0.46037

which, deducted from the measured base, will give its length at the sea level.

Before, however, deducing the real length of the line, the manner of determining the length of the rods must be attended to. Twenty-five feet rods, about $1\frac{3}{4}$ inches by $1\frac{1}{4}$, have been made use of, and four rods placed together, compared with the standard chain. The graduation of one of these rods again may be made with a two-feet Gunter's Brass Standard Scale, and the other three compared with it, as a check on the operation; but such a length and thickness of rod require a large number of stands, or trestles, to support it. For one pair of such rods, nine stands would not be too many, at a distance of $6\frac{1}{4}$ feet apart; twelve-feet rods, therefore, may be deemed preferable. A good Beam Compass, with metal points, may be used for taking off the divisions, which should be laid down several times over by means of dots and arcs; studs of ivory having been for greater accuracy let into the wood, on which the arcs may be drawn; the beam should then a second time be compared with the scale, after the stepping or dividing is concluded, and half the difference (if any) applied as a correction, the thermometer being noted before and after the mean is taken. The two rods, after being divided, must be duly compared with each other, being firmly tied together and laid on a smooth table, planed exceedingly true. The comparison with the steel chain requires that the latter should be fairly stretched with a weight of about 19 lbs., and due allowance made for the expansion of the metal, which has been found to be ·0075 inches for every 1° of Fahrenheit on 100 feet. The employment of the chain in measuring a Base Line not only occupies an immense period of time in the operation itself, but still more so in the preparation of coffers and stands, which latter require elevating screws, and are not to be made without extreme difficulty, in most of the situations in which Surveyors find themselves in this country. An expeditious

method, and one requiring hardly any apparatus, is to drive stout pickets into the ground at distances of twelve feet, and with a rod of this length, well trussed and furnished with points, forming in some measure a large Beam Compass, the exact length may be set off from picket to picket. The measurement being conducted so near the ground occasions, however, great uneasiness in the position, and it is well known how essential an easy position is to correct operations of every kind; the plan may, nevertheless, be found useful, where only a tolerable degree of exactness is necessary.

The Base Line, determined as described above, may be made the origin of a series or of a network of triangles as may be required. After the triangulation has traversed over a certain extent of country (say 150 or 200 miles) one of the computed distances, when conveniently situated for the purpose, is again measured with the same care and attention to minutiæ as were bestowed on the measurement of the original Base Line. The line measured is called the Base of Verification. Its object is by comparing the result of the computation with that of the measurement, to check the error of the triangulation.

Selection of Stations.

After the measurement of the Base Line at the origin of the Survey, the next step is the selection of the Stations for the triangulation, or the division of the country to be surveyed into a series of large triangles, the angles of which are placed at Stations clearly visible from each other.

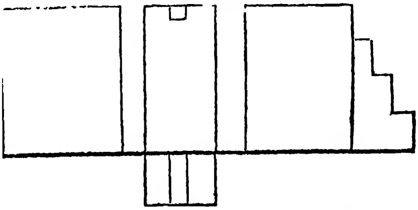
The most conspicuous Stations are selected as Trigonometrical points, and are chosen with reference to their relative positions—as the nearer these triangles approach to being equilateral, the less will be the error in the resulting sides consequent on any slight inaccuracy in the observed angles; but this being difficult in practice, the rule is to admit no angle under 30° or above 90°. The main series of the triangulation should consist of triangles as large as the natural features of the country will admit of—from 15 to 20 miles is a very convenient distance for principal Stations in hilly countries, because objects can be seen at such distances without much difficulty in ordinary conditions of the atmosphere. If, as is frequently the case, the highest peaks are inaccessible, it will be necessary to adopt a lower point, although the greatest effort should of course be made to reach the summit when practicable; in the case of a lower point being used, care must be taken that the view is clear in the direction of the Stations in advance.

It is the practice to mark all spots where angles are taken, whether they be principal or secondary Stations. The mark is a dot with a

concentric circle cut on stone by means of a pointed chisel. If the mark can be engraved on the rock *in situ*, so much the better, otherwise a large stone, properly marked, ought to be buried in the ground; over this a small platform is raised, on the summit of which another mark-stone is inserted, and fixed truly vertical over the lower one. The distance between the two marks should be recorded, but all measurements and observations are usually referred to the upper mark and are stated to be so.

Sometimes, on account of intervening obstacles, it is necessary to raise the platform to a considerable height, in which case several markstones are always inserted and their relative heights recorded.

For Principal Stations it is necessary to make that part of the platform, on which the instrument stands, separate and distinct from that on which the observer and his assistants walk. The instrument is then said to be "duly isolated." Unless this precaution be taken, good angles cannot be expected as the instrument will be liable to irregular disturbance, according to the position of the observer. The annular space between the

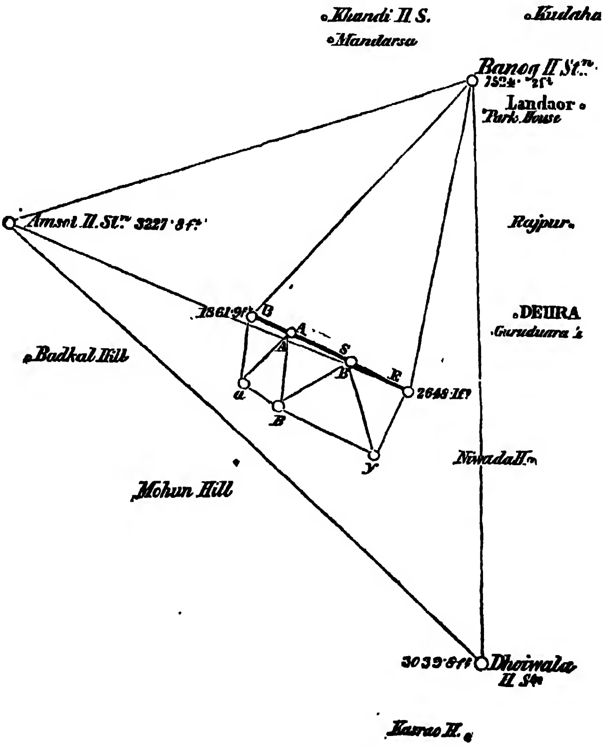


observer's stage and the central pier should be filled up with gravel, or sand, otherwise screws and other parts of the apparatus may be lost. Besides the upper markstone it is usual to imbed on the pier three picked flat heavy stones for the tripod of the instrument to stand upon, these are called "feet stones." It is not usual, if it can be avoided, to make isolated platforms at Secondary Stations; in localities where the ground is very unsteady, such as deep black cotton soil, it may be practicable to steady a Theodolite by using pickets 4 feet long, and driving them into the ground, for the stand of the Theodolite to rest upon, as described in the foot note at page 266. The pickets isolate themselves for at least one foot in driving, but this precaution can only be taken at a new Station, otherwise the mark would be disturbed.

As soon as all the observations have been taken at, and to, any Station, and it is no longer required for the purposes of the Trigonometrical Survey, it should have the pole and brush and pile of stones erected on it, as shewn at page 475, in order that it may be visible to the detail Surveyors. This precaution has the further advantage of protecting the markstones.

As the measured bases average from $5\frac{1}{2}$ to $7\frac{1}{2}$ miles, it will perhaps be useful to point out a convenient method of deriving by means of symmetrical triangles, sides of continuation of 15 to 20 miles in length from a comparatively small measured distance.

On reference to the annexed sketch, which is extracted from Colonel Everest's plan of the Great Arc Series, it will be seen that the first triangle formed upon the measured base is nearly isosceles. If it had been perfectly isosceles with an angle of 30° at the vertex, then the two longest sides which can be derived simultaneously from a given distance would have been obtained: a result, which it will be perceived has been approximated to as nearly perhaps as the configuration of the country would have allowed, by the first triangle in the sketch.



Again, upon one of the long distances (East End Base to Banog) furnished by this triangle, triangle No. 2 is formed, the base whereof ($13\frac{1}{2}$ miles in length) being opposite to the smallest angle, the other two sides

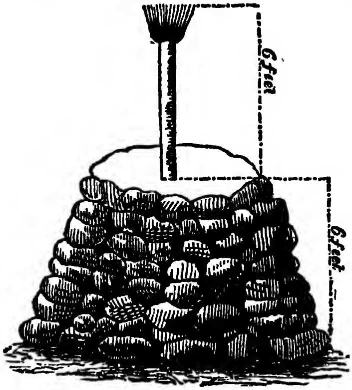
respectively measure 18¼ and 20¾ miles. The longer of these distances (Amsot to Banog) the extremities of which being defined by high peaks, forms therefore a convenient base of continuation, for the extension of the Triangulation to the north and south as may be required.

The signals used for Trigonometrical Surveys in former times were—

Signals.

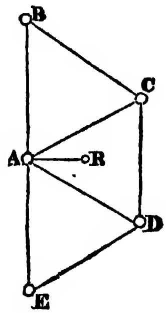
1st. Flags.
2nd. The Pole and Brush.
3rd. Blue Lights.
4th. Vase Lights.

Flags are unfavorable for distant Stations, because the Staff cannot be seen, and the cloth is of course blown aside by the wind. The flags for Principal Stations used to be 12 feet square, one half being blue and the other half white. Those for Secondary Stations are 6 feet square. The blue and white cloth should be placed one above the other, and not side by side. The pole and brush is erected thus. A long straight pole is selected, upon the top of which a brush of twigs is fastened; the pole is placed truly perpendicular over the Station mark, and a pile of stones raised round it, by means of which it is securely fixed. The diagram in the margin will give a clear idea of this signal, which is a very economical and useful opaque object for day observation. The pile of stones may be 5 or 6 feet high, and the pole about as much higher.



Blue lights are very powerful and can be seen at distances of 50 or 60 miles. They are also useful at nearer distances in hazy weather, when other signals are not visible; if not carefully sheltered from the wind by grass screens, the flame is liable to be blown aside. On this account it was the practice of Col. Everest, then Surveyor General of India, to burn them behind an iron screen, in which an aperture had been cut 3 or 3½ inches in diameter, and the centre thereof was duly plummed over the Station mark. The blue light fastened on the end of a stick, was held carefully behind this hole, and no part of the flame could therefore be visible to the distant observer, except through the circular aperture, which having been adjusted over the Station, ensured accuracy.

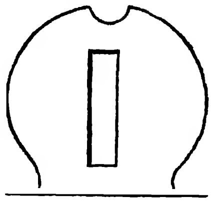
Blue lights being expensive articles cannot be kept constantly burning, but are fired at regular intervals of time by an assistant. They are usually cut in lengths to burn about 4 minutes and are fired at 5 minute intervals, which enables the observer to read off the observation, and also to observe and read off the referring lamp. After every second or third blue light a longer interval of say 10 minutes or ¼ of an hour is allowed to elapse, in order to allow time for changing zero of the instrument, which will be described hereafter. To prevent confusion blue light angles are always taken with a referring lamp as shown in the diagram. Supposing for example the observer is at A and has to observe B, C, D, E, by means of blue lights, a convenient mark is selected at say R about 2 to 3 miles distant, and a lamp is constantly burned there, during the time of night observations, and during the day a flag staff, or sight vane is used. Suppose the blue lights are first fired at station B, then after every intersection of Station B, the readings are noted, the Telescope is then turned to R and the readings thereof noted, whence the angle BAR is deduced by direct observation. Similarly at another period of the same night, or the next night, the ∠ CAR is taken, and so forth, whereby the ∠ BAC may be deduced by the equation BAR—CAR = BAC. The angle CAD by the equation CAR + DAR = CAD and so on. It is a rule, that if any portion of the series of angles is taken with a referring lamp, the whole are to be taken in the same manner, otherwise confusion would arise: also in taking the series of observations required for determining CAR, the readings of R must always be the same within a minute or two, with the view of measuring the angle BAC, on entire arcs of the limb agreeably to the system practised in the Great Trigonometrical Survey, explained in the subsequent part of this Chapter.



Vase lights were invented by Col. Everest nearly 50 years ago, and completely altered the operations of the Great Trigonometrical Survey in India, which had previously to be carried on in the unhealthy season of the rains, in order that the opaque signals, such as flags, might be clearly seen. By enabling observations to be rapidly taken at night, the progress of the work was also much accelerated.

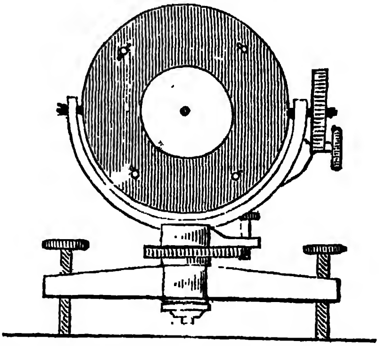
The vase light consists of a common earthen dish about 10 inches in diameter, (more or less according to distance), and filled with cotton seeds and common oil. This is placed upon the station, and to prevent

the flame being blown aside, a large earthen pot, in the side of which an aperture has been cut, is inverted over the dish, as shewn in the diagram, an aperture is also cut in the top to allow the smoke to escape. Further protection is necessary from high wind, by means of grass screens and blankets, leaving merely the requisite opening in the direction of the observer. The materials for this light are procurable in nearly every village.



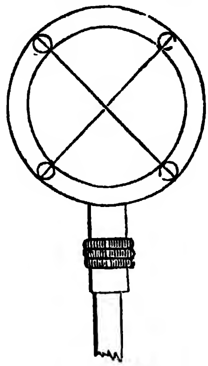
Trigonometrical operations in Southern India were entirely conducted by means of the foregoing signals, more especially the vase light for Principal Stations, and the pole and brush for Secondary Points. During the last 17 years however, signals of modern invention have been employed on account of their superior economy, convenience and power. These consist of Heliotropes, Argand reverberatory lamps, and Drummond lights. The latter surpass all previous contrivances: a ball of lime, about a quarter of an inch in diameter, placed in the focus of a parabolic reflector, and raised to an intense heat by a steam of oxygen gas directed through a flame of alcohol, produces a light eighty times as intense as that given by an Argand burner, and is visible even in hazy weather at a distance of 60 and 80 miles.

The Heliotrope consists of a circular piece of flat plate glass mirror, about 9 inches in diameter, with a small unsilvered aperture in the centre about 0·1 of an inch in diameter as represented in the figure. This mirror is mounted on a frame which stands on a tripod for the sake of steadiness.



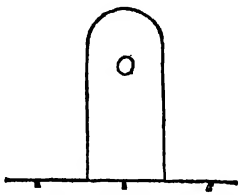
The frame admits of the looking-glass being turned on a horizontal axis as well as on a vertical axis. These two motions in altitude and azimuth are regulated by means of rack work, and they permit the reflection of the sun's rays to be turned in any required direction. In order that it may be directed truly to the observer, a ring with cross-wires, is placed at a distance of about 3 feet; the signal man then looks through the unsilvered aperture in the centre of the Heliotrope and moves the cross-wires until they intersect the distant station. Thus the centre of the Heliotrope, the centre of the wires,

and the observer's station form one right line. Now, if by means of the rack work the mirror is moved in altitude and in azimuth until the sun's rays fall on the wires, it is evident that the light will proceed straight to the observer's Station; but the pencil of rays must be duly bisected by the wires, which intersection can be managed with ease and delicacy, by means of a little circle of white paper placed at the crossing of the wires, upon which paper the reflection of the little aperture in the centre of the mirror may be seen like a small dark speck. When the weather is hazy, the signal man will of course be unable to see the observer's Station, in which case, unless a nearer mark has been given to guide him or a directing line has been drawn for him, he will be so far helpless. Under such circumstances, the observer ought to direct one or more Heliotropes towards the man and keep them playing until he has adjusted his apparatus. Similarly if the man is careless and neglects to keep the sun's rays constantly shining in the true direction, the observer has only to flash a Heliotrope at him, to keep him alert.



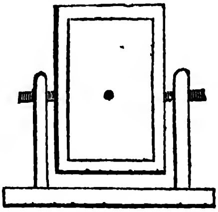
A Heliotrope of 9 inches will answer for 90 or 100 miles; for nearer distances it is much too bright to be observed through a Telescope, and the light must be diminished in the following proportion. For distances of 2 or 3 miles (the usual distance of a referring mark) an aperture of 0·25 of an inch will answer, and for longer distances about 0·1 of an inch of aperture per mile of distance will suffice, *viz.*, an inch for ten miles, 2 inches for 20 miles, and so on, provided always the apparatus is carefully adjusted, and the man, who works it, is alert and skilful.

These apertures are cut in a board which stands upon 3 feet (as shewn in the figure), by means of which the centre of the aperture can be adjusted plumb over the Station mark. This board is called a Sight Vane, and stones are placed on the tail piece to prevent its being disturbed by the action of the wind. If this sight vane be used, the wires before described are unnecessary, because cross-hairs can be fixed in the vane, and will become a substitute for the wires. The Heliotrope is in this case placed 2 or 3 feet in rear of the Sight Vane, and moved laterally and vertically, until the eye applied to the centre unsilvered dot, views the observer's Station and the cross-hairs in one line. The Heliotrope



must be secured in this position, and the means of doing so will readily suggest themselves. It is needless to say that it must be quite firm.

A very good substitute for a regular Heliotrope has been frequently made out of a good looking-glass, with a flat surface. A small hole is drilled through the centre of the back board of the looking-glass, and the silvering scraped off. This aperture should be truly centrical. The looking-glass is then swung in a frame of wood in such a way that the axis of motion shall pass through the unsilvered aperture.



This frame is fixed upon a vertical axis, which ought also to coincide with the unsilvered dot in the mirror. Finally, the vertical axis is planted on a board with three foot screws for adjustment, They have been frequently used with success, on the subordinate series of the Great Trigonometrical Survey as well as in the Revenue Survey, and being powerful as well as economical instruments, they will be found very useful. By means of them and Vase Lights, work can be carried on with great rapidity, because the only limit to the times at which observations can be made will be from 9 o'clock A.M. to $2\frac{1}{2}$ or 3 o'clock P.M. But the Heliotrope is more particularly recommended for the purpose of taking vertical angles with certainty between the hours of $2\frac{3}{4}$ and $3\frac{3}{4}$ afternoon, which is the time of minimum refraction, because verticals, taken at any other times are subject to great irregularities, whereby heights deduced from them are nearly worthless. Luminous objects are much more correctly, rapidly, and comfortably observed than opaque ones, which if distant, are always faint, and disappear when brought near the wire of the Telescope.

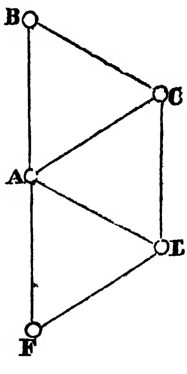
Method of Observing.

In advancing the Field-work, it is necessary that the angles be read on the whole limb of the Theodolite, for thus the error of graduation is obviated. It is also to be borne in mind, that the real basis of all angular measurements is the graduation of the Theodolite. Suppose a 12-inch Theodolite is used, and the sides of a Triangle are about 10 miles, the chord of the angles on the Theodolite will be little more or less than 6 inches, and the accuracy of the angle depends on the graduation defining this chord with great precision. The space on the Theodolite, in fact, represents in miniature the actual space in the Field, hence the necessity for *great care* when angular measurements are concerned. From this follows the necessity to change zero, and to take care that the Theodolite is an absolute fixture; the least shake in the ground ruins

the angle. The instrument must be placed on firm ground, such as rock, or other methods adopted for isolating the instrument from the observer. On account of the want of firmness and immobility of the folding stands for 7-inch and smaller sized Theodolites, they have now been discarded both from the Trigonometrical and Revenue Survey Departments, and braced tripod head-stands substituted as described in page 70.* These also form a good stand for the plane table or drawing board, so that after the angular work is completed, the Surveyor can sketch in the ground. A good 7-inch Troughton and Simms' Theodolite mounted in this way, and always placed on firm ground, unshakable by the observer, will give excellent work for minor triangulation, provided proper signals are used.

All observations taken to elevated objects are subject to two great sources of error, arising from dislevelment of the transit axis, and want of adjustment for the collimation. These causes of error are generally large in small instruments, and although capable of practical adjustment and rectification, still adjustments do not long remain, hence the system of observation should have the property of cancelling all such residual errors. This system is merely change of face, *i.e.*, observing alternately with the vertical face to the right and left, whereby the errors of collimation and dislevelment of transit axis are completely eliminated. Too much regard cannot be paid to this principle in all horizontal angles, whether to elevated or non-elevated objects, for as it is easily practised, so is the effect complete. No confidence can, in fact, be placed in observations on a single face, unless there be *evidence* of the perfect adjustment of the instrument, and such evidence is never forthcoming.

The angles at a Station are taken thus, supposing the observer at A, and the signals, at B, C, D and E, are all visible, the instrument is carefully levelled and adjusted, and so fixed that some Station, B, for instance, reads 0° or zero, then B is called the zero point. Suppose the Telescope to be brought up from the left hand of B and turned gently, so that B may enter the field of view and come near the centre wire, but not pass over it. Then clamp the instrument, and complete the bisection of B by using the tangent screw of slow motion. Read off all the micrometers or verniers, and let an assistant record the readings in a fair legible hand in the angle book. Look again into the Telescope and see that B



* See also "description of New Theodolite Stand" in Appendix D.

remains bisected; if found correct, then carefully unclamp and move the Telescope gently towards C, taking care not to overshoot it; clamp, bisect, and read off as before, and so on for D and E. A complete round of observations at zero 0°, taken by a continuous motion of the instrument from left to right, will thus be obtained. Now overshoot the Station E, and bring the Telescope back by a continuous motion from right to left, observing each Station in succession and recording in readings; this will give a second set at zero 0°, which will suffice. It is the practice of the Trigonometrical Survey to make always one repetition at least, in order that mistakes may not creep in, and pass undiscovered.

Now turn the Telescope over 180° in altitude, and round 180° in azimuth, so that if the face of the vertical circle were previously to the left hand, it will now be to the right hand of the observer, B will then read 180°, and this is called zero 180° FR (face right), the former position being zero 0° FL (face left). Proceed as before, and take two sets of observations, the motion of the instrument being in one set continuous from left to right, and in the other from right to left, as before.

Now if the instrument be supplied with an uneven number of micrometers, three for instance,* it is clear that at zero 0° the readings will be at 0°, 120° and 240°, while the readings at zero 180° will be at 180°, 300°, and 60°, whereby these two zeros give readings at every 60° of the limb. It is the practice on the Great Trigonometrical Survey to take observations at every 10° of the limb for the purpose of eliminating errors of graduation. This object is accomplished by shifting the body of the instrument, so that the zero station may successively read 0°, 10°, 20°, 30°, 40°, and 50°, which, with the respective opposite faces, *viz.*, 180°, 190°, 200°, 210°, 220°, and 230°, gives every 10° of the limb as required.

When two observations of the same angle are made in the way described before on any part of the limb, they will occasionally exhibit a difference much greater than will be warranted by the power of the Theodolite used. When this happens, it is customary to take a third, a fourth, and sometimes even a fifth observation on the same zero, so that the mean result may be affected as little as possible by the discrepancy above adverted to.

Whatever, however, may be the number of observations made on any part of the limb, their arithmetical mean is computed and treated as an integral observation. For an angle therefore which has been observed

* The great or 24-inch Theodolites have five microscopes. The 18-inch instruments have three microscopes; and the 12, 7, 5-inch have three verniers.

on a given number of zeros, there will be the same number of integral observations deduced, the airthmetical mean whereof is the true value of the angle.

It is a fixed rule in the Great Trigonometrical Survey never to reject an observation, unless there be some obvious error in it; the circumstance of its differing, however widely from the mean, is not of itself a sufficient cause for its expunction.

The extent of operations on a Revenue Survey does not, however, call for this extreme precaution, and as the vernier of a 12-inch instrument is graduated to 10 seconds, and by estimation reads 5 seconds, no good purpose would be attained by multiplying observations to the above extent, and readings at every 30° are sufficient. Upon this principle, the zeros to be adopted are 0° and 180°, 30° and 210°, whereby, with two sets at each, there will be eight sets, from which a good mean result may be derived, and a smaller number of observations for primary triangulation of the Revenue or detail Survey would not be satisfactory.

It is clearly to be understood that the change of zero should be regular, that is to say, that the readings should be uniformly distributed at equal intervals round the limb, otherwise, the probability of eliminating the errors of graduations will be diminished.

In the foregoing instructions the signals at all the Stations have been supposed to be simultaneously visible, which is frequently, but not always, the case. It is generally so when lamps are used at night, but when Heliotropes are employed, it is evident that an eastern Station will be seen with difficulty in the morning, whereas in the evening the Heliotropes will shine vividly, and *vice versa* in the case of a western Station; similarly there will be great changes in the appearance of flags as the position of the sun varies. Under these circumstances, the observations cannot always be taken in regular rounds in the simple manner before described. The best plan in this case is to use a referring mark, and connect each Station therewith at such times as may be most convenient for observation.* This arrangement involves the necessity of frequently shifting the instrument so as to return to former zeros, and care must be taken that on each recurrence the referring lamp be made to read nearly the same minutes and seconds as before. It is usual, but not essential, to make the referring lamp the zero Station. If, however, there be among any of the principal Stations to be observed one peculiarly well situated, with every probability of being visible at all hours, it may conveniently

* The method of deducing angles when a referring mark has been made use of, has already been explained at page 476.

be adopted and treated as a referring mark, whereby the extra labor of observing a supplemental point will be saved.

The observations are to be recorded in a book, the method of keeping which will be understood from the subjoined specimen. The headings of the different columns are so explicit, that no further explanation of them appears necessary. The written characters L and R in the column entitled "face and zero," mean face left and face right, alluding to the position of the vertical circle, and the figures 0°, 180°, &c., annexed to those characters, refer to the zeros.

SPECIMEN OF THE ANGLE BOOK.

Morning Angles taken at Durgapur Hill Station, 29th February 1844.

Objects.	Face and Zero.	Micrometer Readings.											Angles.			Remarks.
		A			B		C		Means							
		°	′	″	′	″	′	″	°	′	″		°	′	″	
Phuljori, Heliotrope ..	R 180°	237	37	4·2	36	15·5	37	15·4	237	36	51·70		57	36	7·83	
Ghati " ..		179	60	50·2	59	50 9	61	30·5	180	0	43·87					
Ghati " ..		179	60	50·0	59	50·6	61	30·8	180	0	43·80					
Phuljori " ..		237	37	1·5	36	10·1	37	12·0	237	36	47·87		57	36	4·07	
Phuljori " ..	L 0°	57	36	6·0	36	28·6	37	41·2	57	36	45·27		57	36	9·90	
Ghati " ..		0	0	11·8	0	32·0	1	2·3	0	0	35·37					
Ghati " ..		0	0	13·0	0	31·7	1	4·4	0	0	37·37					
Phuljori " ..		57	36	8·0	36	33·5	37	42·0	57	36	47·83		57	36	10·46	
Phuljori " ..	L 10°	67	36	14·7	36	34·1	37	40·9	67	36	49·90		57	36	9 00	
Ghati " ..		10	0	11·5	0	40·4	1	10·8	10	0	40 90					
Ghati " ..		10	0	14·8	0	43·5	1	14·4	10	0	44·23					
Phuljori " ..		67	36	14·1	36	34·5	37	41·7	67	36	50·10		57	36	5·87	

Afternoon Angles taken at Durgapur Hill Station, 29th February 1844.

Objects.	Face and Zero.	A °	A ′	A ″	B ′	B ″	C ′	C ″	Means °	Means ′	Means ″	Angles °	Angles ′	Angles ″	Remarks.
Phuljori, Heliotrope ..	R 190°	247	37	32·9	36	27·4	37	38·6	247	37	12·97	57	36	14 24	
Ghati " ..		189	61	8·1	59	57·7	61	50·4	190	0	58·73				
Ghati " ..		190	1	10·5	0	0 9	1	54·5	190	1	1 97				
Phuljori " ..		247	37	37·6	36	30·2	37	43·2	247	37	17 00	57	36	15·03	
Phuljori " ..	L 20°	77	36	48·3	36	54 0	38	22·4	77	37	21·57	57	36	1·77	
Ghati " ..		20	0	45·6	1	10 2	2	3 6	20	1	19·80				
Phuljori " ..		77	36	54·8	36	55·2	38	25·8	77	37	25 27	57	36	4·07	
Ghati " ..		20	0	46·8	1	6·3	2	10 5	20	1	21 20				
Phuljori " ..	R 200°	257	37	44·5	36	51·0	37	50·7	257	37	28·73	57	36	10·00	
Ghati " ..		200	1	28·7	0	19·5	2	8·0	200	1	18·73				
Ghati " ..		200	1	31·5	0	23·2	2	12·7	200	1	22·47				
Phuljori " ..		257	37	51·1	36	52·5	37	52·3	257	37	31·97	57	36	9 50	

Night Light Angles taken at Durgapur Hill Station, 29th February 1844.

Objects.	Face and Zero.	Micrometer Readings. A °	A ′	A ″	B ′	B ″	C ′	C ″	Means °	Means ′	Means ″	Angles °	Angles ′	Angles ″	Remarks.
Phuljori, Lamp ..	L 30°	87	36	36·9	36	38·3	38	8 0	87	37	7·73	57	36	3·56	
Ghati ,, ..		30	0	29·5	0	49 3	1	53·	30	1	4 17				
Ghati ,, ..		30	0	31·0	0	53·7	1	56·9	30	1	7·20				
Phuljori ,, ..		87	36	35·3	36	40·3	38	9·2	87	37	8·27	57	36	1·07	
Ghati ,, ..	R 210°	210	1	7 7	0	2·5	1	49·5	210	0	59·90	57	36	13·43	
Phuljori ,, ..		267	37	28·1	36	39·4	37	32·5	267	37	13 33				
Phuljori ,, ..		267	37	30·0	36	40 7	37	33 5	267	37	14·73				
Ghati ,, ..		210	1	15·1	0	9·4	1	53 2	210	1	5 90	57	36	8·83	
Ghati ,, ..	R 220°	220	1	37·8	0	27·0	2	7·9	220	1	24·23	57	36	14·84	
Phuljori ,, ..		277	37	49·0	37	11·1	37	57·1	277	37	39 07				
Phuljori ,, ..		277	37	44·9	37	6·4	37	50·7	277	37	34·00				
Ghati ,, ..		220	1	41 1	0	25·3	2	11·4	220	1	25 93	57	36	8 07	
Ghati ,, ..		220	1	41 0	0	25·2	2	9·8	220	1	25 33	57	36	10·70	
Phuljori ,, ..		277	37	46 5	37	5·5	37	56 1	277	37	36 03				
Ghati ,, ..	L 40°	40	1	1·8	1	6 3	2	14 8	40	1	27·63				
Phuljori ,, ..		97	37	1·7	37	5 8	38	27·5	97	37	31·67	57	36	4·04	
Phuljori ,, ..		97	36	55·7	37	5 2	38	27·9	97	37	29·60	57	36	1·13	
Ghati ,, ..		40	0	52 2	1	5·0	2	28 2	40	1	28 47				
Ghati ,, ..	L 50°	50	0	13·5	0	29 2	1	52·1	50	0	51·60				
Phuljori ,, ..		107	36	30 5	36	18 0	38	5·5	107	36	58·00	57	36	6·40	
Phuljori ,, ..		107	36	24·2	36	21·0	37	60·1	107	36	55·10	57	36	1·63	
Ghati ,, ..		50	0	14·3	0	29·6	1	56·5	50	0	53·47				
Ghati ,, ..	R 230°	229	61	2·1	59	50·5	61	27·2	230	0	46 60				
Phuljori ,, ..		287	37	9·1	36	36·8	37	8·8	287	36	58 23	57	36	11·63	
Phuljori ,, ..		287	37	12·6	36	42 0	37	9·4	287	37	1·33	57	36	16·70	
Ghati ,, ..		229	61	4·3	59	48·0	61	21·6	230	0	44 63				

Synopsis of the foregoing Observations, arranged under their respective Zeros.

∠ Ghati and Phuljori, 57° 36′

0°	180°	10°	190°	20°	200°	30°	210°	40°	220°	50°	230°
9″90 10·46	7″83 4·07	9″00 5·87	14″24 15·03	1″77 4·07	10″00 9·50	3″56 1·07	13″43 8·83	4″04 1·13	14″84 8·07 10·70	6″40 1·63	11″63 16·70
10·18	5·95	7·44	14·64	2·92	9·75	2·32	11·13	2·59	11·20	4·02	14·17

General Mean 57° 36′ 8·″03.

DURGAPUR HILL STATION DESCRIBED.

"Durgapur Hill Station is situated about a mile east of the village of the same name in the Jungul Mehals Midnapur District. It has the respectable village of Pandra about 4 miles S.W. There are two roads to the station from Durgapur village, the shortest or the one directly east is steep, while the other, which commences from the north foot of the hill, is of gradual ascent and circuitous. A platform points out the station of observation. It has another hill about 5 miles north called Budmah, which is also marked.

The Angle Book should on no account ever be suffered to fall in arrears. The original should be examined by two computers, and attested by their signatures, and the name of the observer should be recorded. The duplicate should be compared with the original by two persons, and likewise attested by their signatures. It is a standing rule in order to exclude errors, that all computations and comparisons should be performed independently by two persons, and attested by their signatures, and unless such precautions have been observed, the results are considered untrustworthy as final work.

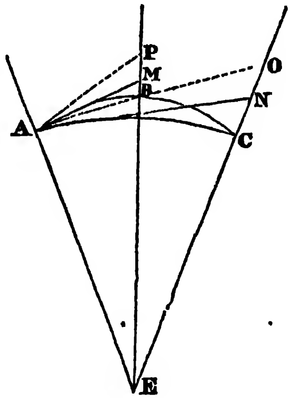
It is convenient to keep an Observatory Memorandum Book for the purpose of registering all sorts of remarks, and it is usual to insert in this book the results of observations, as they are taken, in order that the observer may be able to see at a glance how the work is progressing..

CHAPTER IV.

THE COMPUTATION OF GEODETICAL TRIANGLES.

WITH respect to the angles thus observed, and the triangles formed from them, they are not, rigorously speaking, *plane*, but *spherical*, existing on the surface of a sphere, or rather, to speak correctly, of a spheroid. In small triangles, of six or seven miles in the sides, this consideration may be neglected as the difference is imperceptible; but in larger ones it must be taken into consideration.

"It is evident that as every object used for pointing the telescope of a Theodolite has some certain elevation, not only above the soil, but above the level of the sea; and as, moreover, these elevations differ in every instance, a reduction to the horizon of all the measured angles would appear necessary. But in fact, by the construction of the Theodolite, which is nothing more than an altitude and azimuth instrument, this reduction is made in the very act of reading off the horizontal angles.



"Let E be the centre of the earth; A, B, C, the places on its spherical surface to which the three stations, A, P, O, in a country are referred, by radii EA, EBP, ECO. If a Theodolite be stationed at A, the axis of its horizontal circle will point to E when truly adjusted, and its plane will be a tangent to the sphere at A, intersecting the radii EBP, ECO, at M and N, above the spherical surface. The telescope of the Theodolite, it is true, is pointed in succession to P and O; but the readings of its azimuthal circle give,—*not* the angle PAO between the directions of the telescope, or between the objects, P, O, as seen from A, but the azimuthal angle MAN, which is the measure of the angle A of the spherical triangle BAC.

"The true way then of conceiving the subject of a Trigonometrical Survey, when the spherical form of the earth is taken into consideration, is to regard the network of triangles into which the country is divided, as the bases of an assemblage of pyramids converging to the centre of the earth. The Theodolite gives us the true measures of the angles included by the planes of those pyramids; and the surface of an imaginary sphere at the level of the sea, intersects them in an assemblage of spherical trian-

gles, above whose angles, in the radii prolonged, the real stations of observation are raised by the superficial inequalities of mountain and valley."*

Having shewn that the triangles described upon the surface of the earth are spherical triangles, we will now proceed to lay down the rules by which they may be computed.

One property of a spherical triangle is, that if its three angles were added together, their sum would be greater than π or 180°.† Calling therefore A, B, C, the angles of a spherical triangle, we shall have $A + B + C = \pi + e$.

The term e by which the sum of the angles exceeds a semicircle or π, is called the spherical excess of the triangle.

On a little consideration it will be evident that the computation of the spherical excess of a triangle is a circumstance of great moment, for unless that term be known, the accuracy with which the angles have been observed can never be ascertained, nor, as it will afterwards appear, can the triangle itself be computed as a spherical triangle.

The rigorous formula as established by writers on spherical trigonometry for the computation of the spherical excess, is this:—

$$Tan\ \tfrac{1}{2}\ e = \frac{\tan \frac{1}{2} b.\ \tan \frac{1}{2} c.\ \sin A}{1 + \tan \frac{1}{2} b.\ \tan \frac{1}{2} c.\ \cos A}$$

in which b and c represent the two spherical sides, the former being opposite to B and the latter to C.

Although this formula for the spherical excess possesses a neat and compact form, it is far from being susceptible of an easy arithmetical computation, particularly when it is applied to such triangles as those presented by a Trigonometrical Survey of an ordinary description. To adapt the formula therefore to this exigency, it will require to be evolved into a series. This done, and putting r for the mean radius of the earth, the value of e in seconds will stand as follows:—

$$\begin{aligned} e'' = {} & \frac{bc \sin A}{2} \cdot \frac{\operatorname{cosec} 1''}{r^2} \\ & + \frac{b^3 c \sin A}{24} \cdot \frac{\operatorname{cosec} 1''}{r^4} \\ & + \frac{bc^3 \sin A}{24} \cdot \frac{\operatorname{cosec} 1''}{r^4} \\ & + \frac{b^2.c^2 \sin 2A}{16} \cdot \frac{\operatorname{cosec} 1''}{r^4} \end{aligned}$$

* Herschell's Astronomy.

† Ramsden's large Theodolite, three feet in diameter, was the first instrument by which this excess, called the spherical excess, was observed. It is always a minute quantity, seldom exceeding 4″ to 5″ in the triangles used in geodetical operations.

In this series the first term is only effective, and the other terms, being very minute, may be thrown out of consideration. Supposing b and c to be given in terms of some linear unit, it is evident that $\frac{bc \sin A}{2}$ will represent the area of the given spherical triangle computed as a plane one, such an area therefore multiplied by the constant ratio $\frac{\text{cosec } 1''}{r^2}$ will give the spherical excess in seconds.*

In practice, however, the distances b and c are rarely known, the given elements being generally one side a, and the three angles A, B, and C.

If, therefore, the area of the triangle be required in terms of these elements, it will be equivalent to $\frac{a^2 \sin B \sin C}{2 \sin A}$.

The computation of the spherical excess of a triangle does not demand that its angles and sides should be known to any degree of nicety. It will be sufficient if the former are taken at their observed values to the nearest second: altering these values when required by equal amounts to make their sum amount to π. Either from these data, or from the sides derived therefrom, the spherical excess may be deduced, which will be true to within the limits of accuracy usually required in practice.

As an example of the computation of the spherical excess take the 23rd triangle from p. 261 of Colonel (then Capt.) Everest's account of the measurement of the Great Indian Arc, published in 1830, assuming the mean radius of the earth to be 20888153·2 feet, which is the numerical value of r in the formula before given.

Yemsha to Shevalingapah a = 136352·62 *feet Log.* 5·1346620.

Stations.	Characteristic marks.	Observed Angles.			Seconds of corrected Angles.	Sines of corrected Angles.	Computed sides.
		°	′	″	″		
Yemsha ...	C	70	56	45·966	41	9·9755256	
Shevalingapah	B	59	4	9·423	4	9·9333739	
Yaenagapally ...	A	49	59	20·567	15	9·8841744	
Yaenagapally to Yemsha				b = ...		Feet	152708
						Log	5·1838615
Ditto to Shevalingapah				c = ...		Feet	168278
						Log	5·2260132

* The factor $\frac{\text{cosec } 1''}{2r^2}$ is given for all Indian Latitudes in III of Auxiliary Tables, G. T. Survey.

SPHERICAL EXCESS COMPUTED.

First Process.

	Log. b	5·1838615
	Log. c	5·2260132
	Log. sin. A... ...	$\bar{1}$·8841744
A. C	Log. 2	$\bar{1}$·6989700*
	Log. cosec 1″ ...	5·3144251
A. C.	Log. r	$\bar{8}$·6800999
		$\bar{8}$·6800999
	Log. e	0·6676440

$e = 4''{\cdot}652$

Second Process.

	Log. a	5·1346620
		5·1346620
	Log. sin. B. ...	$\bar{1}$·9333739
	Log. sin. C. ...	$\bar{1}$·9755256
	Log. cosec A ...	0·1158256
A. C.	Log. 2	$\bar{1}$·6989700*
	Log. cosec 1″ ...	5·3144251
A. C.	Log r.	$\bar{8}$·6800999
		$\bar{8}$·6800999
	Log. e	0·6676440

$e = 4''{\cdot}652$

Now let A' be the observed value of A, B' that of B, and C' that of C; it is evident that $A' + B' + C'$ will never be equal to $\pi + e$, but will either be in excess or in defect of this amount.

This last circumstance may be expressed algebraically in the following manner: $A' + B' + C' = \pi + e - \epsilon$, in which $\pi + e$ standing for the true sum of the angles, ϵ will be the error of observation.

In the triangle given above, the sum of the three angles $= \pi + 15''{\cdot}956$, and $e = 4''{\cdot}652$; therefore $\epsilon = 11''{\cdot}304$.

It is clear that nothing certain can be advanced as to the origin of this error. It may be that the signals were not properly centered, or that the graduation and the adjustments of the instrument were imperfectly executed; or lastly, that there was a peculiarity or a defect in the eye of the observer. All these circumstances may have operated separately, or in combination, to produce the discrepancy under consideration.

Supposing, however, that the three angles of the triangle have been taken with the same instrument, and with the same care, and by the same observer, it is extremely probable that each is liable to an equal amount of error. If this be admitted, it will follow that the best way of expunging ϵ, is by apportioning it equally amongst the three observed angles†.

* It greatly facilitates computation by combining these four Logarithms into one sum and treating it as a constant Log.

† All triangular and other corrections are now determined by the "Method of least squares."

If the angles of the triangle before given are corrected by this process, they will stand as follows:

Stations.	Observed Angles.			Apportionment of Error.	Corrected Angles.		
Yemsha	70°	56′	45″·966	— 3″·768	70°	56′	42″·198
Shevalingapah ...	59	4	9·423	— 3·768	59	4	5·655
Yaenagapally ...	49	59	20·567	— 3·768	49	59	16·799
	180	0	15·956	11·304	180	0	4·652

The angles given in the last column are called spherical angles. Their sum amounts (as it ought to do) to $\pi + e$. After the observed angles have been reduced to their spherical values, the computation of the geodetical triangle may be taken in hand.

Of the different deductive processes established by different writers for the accomplishment of this object, that laid down by Le Gendre possesses superior advantages on the score of its simplicity, expedition, and accuracy. It is based on the assumption that the sides of a geodetical triangle, which may be presented for computation, are very small in comparison with the radius of the earth; and it has been discovered by actual calculation, that a triangle, whose sides do not exceed 450 miles, may be deduced by Le Gendre's theorem without producing an error of one foot in the result.

This theorem for the computation of a geodetical triangle may be stated as follows:—From each of the spherical angles of the triangle, deduced as directed in the former part of this chapter, deduct one-third of the spherical excess. With the angles so diminished, compute the sides of the triangle by the rules of plane trigonometry,—these sides (such is the result of Le Gendre's investigation) will be equivalent in length to the spherical sides of the given geodetical triangle. It may be added, that when the spherical angles of a geodetical triangle are diminished by one-third of the spherical excess, they are called angles for computation, and that their sum must obviously amount to 180°.

In the Great Trigonometrical Survey of India, Le Gendre's theorem is made use of in the computation of the principal triangulation. As an example of which, let us take the triangle before given.

Yemsha to Shevalingapah = 136352·16 *feet. Log.* 5·1346620.

Stations.	Spherical Angles.	Angles for Computation.	Sines.	Deduced Sides.
Yemsha	70° 56′ 42″·198	70° 56′ 40″·647	9·9755253	
Shevalingapah ...	59 4 5·655	59 4 4·104	9·9333740	
Yaenagapally	49 59 16·799	49 59 15·249	9·8841748	
Yaenagapally to Yemsha			Feet ...	152707·77
			Log. ...	5·1838612
Ditto to Shevalingapah			Feet ...	168272·23
			Log. ...	5·2260125

Computation of the Sides Exhibited.

First Side.

Yemsha to Shevalingapah	Log.	5·1346620
∠ Yaenagapally	cosec. or A. C. of sin.	0·1158252
∠ Shevalingapah	sin.	9·9333740
Yaenagapally to Yemsha	Log.	5·1838612
	Feet	152707·77
	Miles	28·922

Second Side.

Yemsha to Shevalingapah	Log.	5·1346620
∠ Yaenagapally	cosec. or A. C. of sin.	0·1158252
∠ Yemsha	sin.	9·9755253
Yaenagapally to Shevalingapah	Log.	5·2260125
	Feet	168272·23
	Miles	31·870

The process of computation, described in the foregoing pages, is applicable to the principal triangulation of a series. In the deduction of the Secondary Triangles however, such for instance as those for a Topographical Survey, all this attention to minutiæ is never required, it being sufficient to consider these as plane triangles, and compute them accordingly.

CHAPTER IV.]

There is only one circumstance connected with the deduction of Secondary Triangles, which stands in need of some explanation at this place. In some Secondary Triangles, only two angles are observed, and in others all three. In the former case, the two angles are added together, and the sum is deducted from π, resulting difference is the third or the supplemental angle. In the latter case, the sum of the three angles is compared with π, and if any difference exist between the two amounts, it is apportioned equally amongst the three angles, employing the angles so corrected in the computation of the triangle.

The following examples extracted from the Report of the Great Trigonometrical Survey, will illustrate these methods of computation:

Pirer to Paniari = 15441·8 *feet, Log.* 4·1886970.

Stations.	Observed Angles.	Apportionment of Error.	Angles for Computation.	Sines.	Deduced Sides.
Pirer ...	53° 26′ 57·5	+ 1″·4	53° 26′ 59″	9·9048965	
Paniari ...	70 9 44·0	+ 1·5	70 9 45	9·9734322	
Mirpur ...	56 23 14·2	+ 1·4	56 23 16	9·9205424	
	179 59 55·7	4·3	180 0 0	....	
Mirpur to Pirer				Feet ...	17441·6
				Log. ...	4·2415868
Ditto to Paniari				Feet ...	14895·4
				Log. ...	4.1730511

Paniari to Mirpur = 14895·4 *feet, Log.* 4·1730511.

Stations.	Observed Angles.	Apportionment of Error.	Angles for Computation.	Sines.	Deduced Sides.
Paniari ...	94° 51′. 18	......	94° 51′ 18″	9·9984390	
Mirpur ...	22 29 38	......	22 29 38	9·5827278	
Tajpur Village Tree Flag.	Supplemental Angle.	......	62 39 4	9·9485233	
	....	......	180 0 0	....	
Tajpur to Paniari...				Feet ...	6416
				Log. ...	3·8072556
Ditto to Mirpur				Feet ...	16710
				Log. ...	4·2229668

CHAPTER V.

THE COMPUTATION OF LATITUDES, LONGITUDES, AND AZIMUTHS OF TRIGONOMETRICAL STATIONS.

LET A and B be two Trigonometrical Stations. The latitude and longitude of A, together with the distance of A to B at the sea level, and the azimuth of the line as appears to an observer at A, being given, it is required to deduce the latitude and longitude of B and the azimuth of the same line BA as appears to an observer at B.

The symbols which are usually made use of to represent the elements given, as well as those required, are as follow:

Elements given.		*Elements sought.*	
λ	Latitude of A	λ'	*Latitude of B*
L	Longitude of ditto	L'	*Longitude of ditto*
A	Azimuth of B from A*	B	*Azimuth of A from B.*
c	Distance from A to B.		

Of the foregoing seven symbols, two only, namely A and B, which stand for azimuths, require some explanation. In the Revenue Survey the origin of the azimuthal arc is placed in north, whence it proceeds by east to south, and thence again it returns by west to north. This is the common mode of reckoning the azimuth.

In the formulæ which will be given hereafter, the azimuthal arc will be taken to commence from south, and to proceed by west and north, round the whole circle of the horizon, as observed in the Great Trigonometrical Survey. According to this view the azimuth of west will be 90°, that of north 180°, and lastly, that of east 270°.

It is necessary to mention at this place that there are two solutions of the problem under consideration, the spherical and the spheroidal. In the former the earth is supposed to be a sphere, in the latter it is taken as a spheroid. In this work we will adopt the spheroidal solution in the first place, because it is more consonant to truth than the other; and secondly, because the process of computation it gives rise to has been arranged by Col. G. Everest, formerly Surveyor General of India, into a form

* The method of deriving the first or fundamental azimuth at the origin of the triangulation, will be found in Part V.

which is susceptible of easy and convenient application to survey operations.

In the computation of the Great Trigonometrical Survey of India, the dimensions of the earth supposed to be a spheroid are taken at the following values:

$$\text{Axis Major } a = 20922931{\cdot}8 \text{ feet}$$
$$\text{Ditto Minor } b = 20853374{\cdot}6 \text{ feet}$$

These elements are derived from a comparison of the Dodagontah arc, comprised between Punnæ and Kalianpur, measured prior to the year 1826, with the French arc, beginning at Greenwich and ending at Formentera.

On a slight consideration it will be evident that if the differences $(\lambda'-\lambda)$, $(L'-L)$, $(B-\overline{\pi+A})$ could be computed by any process, λ', L' and B could be easily deduced therefrom.

For instance, supposing $\lambda'-\lambda=\Delta\lambda$, $L'-L=\Delta L$, and $B-(\pi+A)=\Delta A$, we shall have $\lambda'=\lambda+\Delta\lambda$; $L'=L+\Delta L$; and $B=(\pi+A)+\Delta A$.

The reason why these differential quantities, $\Delta\lambda$, ΔL, ΔA, are computed in preference to λ', L' and B, is, that the former are susceptible of easier and more accurate deduction than the latter.

On reference to pp. 161 and 169 of Col. Everest's account of the Indian Arc published in 1847, it will be seen that the values of $\Delta\lambda$, ΔL, and ΔA come out in infinite series. These series are rapidly convergent: Col. Everest uses only the first four terms, and omits the others on account of their minuteness. For the purposes of this work, however, the first and second terms are all which will be required, the third and the fourth terms, which are retained by Col. Everest, being too minute to merit attention at this place.

Limited to the 2nd term, the formulæ for the computation of latitudes, longitudes and azimuths, as arranged by Col. Everest, are as follow:

For Latitude.	*For Longitude.*	*For Azimuth.*
$\delta_1\lambda = P.\cos A.\,c$	$\delta_1 L = \delta_1\lambda.\,Q.\sec\lambda.\tan A$	$\delta_1 A = \delta_1 L.\sin A.$
$\delta_2\lambda = \delta_1 A.\,R.\sin A.\,c$	$\delta_2 L = \delta_2\lambda.\,S.\cot A$	$\delta_2 A = \delta_2 L.\,T.$
	in which	
$\delta_1\lambda + \delta_2\lambda = \Delta\lambda$	$\delta_1 L + \delta_2 L = \Delta L.$	$\delta_1 A + \delta_2 A = \Delta A.$

The terms $P, Q, R, S, T \ldots$, which occur in these formulæ, are composed of the numerical values of a and b given before, and of certain functions of the given latitude λ. Most of these terms are of tedious deduction, on which account it becomes necessary that they should be computed once for all, and registered under a Tabular Form, so as to be ready for use when required.

Accordingly, in the Great Trigonometrical Survey of India, we have the new table of P, Q, R, ... computed for every 10′ of latitude between the parallels of 5° and 36°; and we will give at the end of this Chapter an extract from this table, which will facilitate computations by Col. Everest's formulæ.*

The arrangement of this table is so simple that it hardly requires any explanation. Enter the table with the given latitude λ of station A. If λ is exactly found in the table, take out P, Q, R, ... just as they stand in a line therewith. This is a very simple operation, but the exact agreement which we have supposed to exist between the given and the tabular latitude, seldom takes place in practice. In most instances the given latitude will lie between two tabular latitudes. In such cases take out P, Q, R, ... appertaining to the next less tabular latitude and correct them in this wise. Take the difference between the given and the tabular latitude next less, and convert it to the denomination of a minute. The term so obtained being multiplied successively by the tabular differences for P, Q, R, S and T, and divided by 10, will furnish the required corrections, which will be negative in the case of P, R and T, and positive in that of Q and S.

P, Q, R, S, T being computed, other terms of the formulæ, such for instance as cos. A, tan. A, sec. λ, sin. λ ......, may be taken out from a common table of logarithms.

When the terms $\delta_1\lambda$, $\delta_1 L$, ... are computed, they will be in seconds and decimals thereof.

The signs of these terms dependant upon the magnitude of the given azimuth A, may be easily taken out from the following table :—

Terms of the Formulæ.	Magnitude of the given Azimuth A.			
	1st Quadrant.	2nd.	3rd.	4th.
$\delta_1\lambda$	—	+	+	—
$\delta_1 L$	—	—	+	+
$\delta_1 A$	—	—	+	+
$\delta_2\lambda$	—	—	—	—
$\delta_2 L$	+	—	+	—
$\delta_2 A$	+	—	+	—

* See Auxiliary Tables of the G. T. Survey (Table IV).

After proper signs have been prefixed to $\delta_1\lambda$, $\delta_1 L$, take the sums of $\delta_1\lambda$ and $\delta_2\lambda$; of $\delta_1 L$ and $\delta_2 L$; and of $\delta_1 A$ and $\delta_2 A$. The three sums so obtained will be the values, the first of $\Delta\lambda$, the second of ΔL, and the last of ΔA.

Now $\Delta\lambda$ being applied to λ, ΔL to L, and ΔA to $(\pi+A)$, the resulting elements will be λ', and L' and B.

By way of illustrating the computation of the latitudes, longitudes and azimuths of Trigonometrical Stations, we annex an example on pages 497-8.

When a point is determined by a triangle, it ought to have two deductions of latitude, longitude and azimuth derived from the Stations defining the base of the triangle. For instance, referring to triangle at page 491, Yaenagapally may be computed from Yemshaw, as well as from Shevalingapah. In the Great Trigonometrical Survey, it is the invariable practice to go through the two deductions and compare the results, which, when the two computations are correctly executed, will be identical.

Shevalingapah deduced from Yemshaw.

Station A Yemshaw.			Station B Shevalingapah.
$\lambda = 18°\ 51'\ 31''{\cdot}00$			$A = 73°\ 1'\ 52''{\cdot}11$
$L = 78\ \ 1\ \ 0{\cdot}79$			Log. c = 5·1346620
P.	...	3·9962429	
Cos$A$	...	$\bar{1}$·4651625	
c ...	...	5·1346620	
$\delta_1\lambda$ ...	...	2·5960674	...... $-$ 394″·52 = $-$ 0° 6′ 34″·52
Q ...	...	$\bar{1}$·9974090	
Sec λ	...	0·0239624	
Tan A	...	0·5155059	
$\delta_1 L$ ...	...	3·1329447	...... $-$ 1358″·14 = $-$ 0° 22′ 38″·14
Sin λ...	...	1·5095169	
$\delta_1 A$ ...	...	2·6424616	...... $-$ 439″·00 = $-$ 0° 7′ 19″·00
R ...	...	$\bar{8}$·38079	
Sin A	...	$\bar{1}$·98067	
c ...	...	5·13466	
$\delta_2\lambda$ ...	...	0·13858	...... $-$ 1″·38

S ...	...	0·32241	
Cot A	...	$\bar{1}$·48449	
$\delta_2 L$ ...	...	1·94548	0″·88
T ...	...	0·23472	
$\delta_2 A$ ...	...	0·18020	...... + 1″·51
$\delta_1 \lambda$	= −	0° 6′ 34″·52	
$\delta_2 \lambda$	= −	1·38	
$\Delta\lambda$	= −	0 6 35·90	
λ	=	18 51 31·00	
λ'	=	18 44 55·10	Deduced Latitude of Shevalingapah.
$\delta_1 L$	= −	0 22 38·14	
$\delta_2 L$	= +	0·88	
ΔL	= −	0 22 37·26	
L	=	78 1 0·79	
L'	=	77 38 23·53	Deduced Longitude of Shevalingapah.
$\delta_1 A$	= −	0 7 19·00	
$\delta_2 A$	= +	1·51	
ΔA	= −	0 7 17·49	
$\pi + A$	=	253 1 52·11	
B	=	252 54 34·62	Deduced Azimuth of Yemshaw from Shevalingapah.

Table exhibiting the Logarithmic values of P, Q, R, S, and T, between the parallels of 18° *and* 35° *of Latitude.*

λ	P	Diff.	Q	Diff.	R	Diff.	S	Diff.	T	Diff.
18° 0′	$\bar{3}$·9962818	—75	$\bar{1}$·9973831	+50	$\bar{8}$·38083	—1	0·32021	+41	0·25077	—320
10	2743	73	3881	48	82	1	062	42	4757	317
20	2670	77	3929	52	81	1	104	43	4440	312
30	2593	75	3981	50	80	0	147	43	4128	307
40	2518	77	4031	51	80	1	190	44	3821	303
50	2441	76	4082	51	79	1	234	43	3518	300
19 0	$\bar{3}$·9962365	78	$\bar{1}$·9974133	52	$\bar{8}$·38078	1	0·32277	45	0·23218	296
10	2287	78	4185	52	77	0	322	44	2922	293
20	2209	81	4237	54	77	1	366	45	2629	288
30	2128	79	4291	53	76	1	411	46	2341	284
40	2049	80	4344	53	75	1	457	46	2057	281
50	1969	81	4397	54	74	1	503	46	1776	277
20 0	$\bar{3}$·9961888	81	$\bar{1}$·9974451	54	$\bar{8}$·38073	0	0·32549	47	0·21499	275
10	1807	82	4505	55	73	1	596	47	1224	270
20	1725	80	4560	53	72	1	643	47	0954	266
30	1645	84	4613	56	71	1	690	48	0688	264
40	1561	84	4669	56	70	1	738	49	0424	260
50	1477	84	4725	56	69	1	787	49	0164	258
21 0	$\bar{3}$·9961393	84	$\bar{1}$·9974781	56	$\bar{8}$·38068	0	0·32836	49	0·19906	253
10	1309	85	4837	57	68	1	885	50	9653	251
20	1224	86	4894	57	67	1	935	50	9402	247
30	1138	85	4951	57	66	1	985	50	9155	244
40	1053	89	5008	59	65	1	0·33035	51	8911	243
50	0964	84	5067	56	64	1	086	52	8668	237
22 0	$\bar{3}$·9960880	90	$\bar{1}$·9975123	60	$\bar{8}$·38063	1	0·33138	52	0·18431	236
10	0790	87	5183	58	62	0	190	52	8195	232
20	0703	90	5241	60	62	1	242	52	7963	231
30	0613	90	5301	60	61	1	294	54	7732	226
40	0523	88	5361	59	60	1	348	53	7506	224
50	0435	91	5420	60	59	1	401	54	7282	221
23 0	$\bar{3}$·9960344	91	$\bar{1}$·9975480	61	$\bar{8}$·38058	1	0·33455	55	0·17061	219
10	0253	91	5541	61	57	1	510	55	6842	216
20	0162	92	5602	61	56	1	565	55	6626	217
30	$\bar{}$ 0070	93	5663	62	55	1	620	56	6412	214
40	$\bar{3}$·9959977	92	5725	61	54	1	676	56	6202	200
50	9885	94	5786	63	53	1	732	56	5994	208
24 0	$\bar{3}$·9959791	93	$\bar{1}$·9975849	62	$\bar{8}$·38052	1	0·33788	58	0·15787	202
10	9698	95	5911	63	51	0	846	57	5585	201
20	9603	96	5974	64	51	1	903	58	5384	198
30	9507	96	6038	65	50	1	961	59	5186	196
40	9411	94	6103	62	49	1	4020	58	4990	194
50	9317	96	6165	64	48	1	078	60	4796	191
25 0	$\bar{3}$·9959221	96	$\bar{1}$·9976229	64	$\bar{8}$·38047	1	0·34138	59	0·14605	189
10	9125	99	6293	66	46	1	197	61	4416	186
20	9026	97	6359	64	45	1	258	60	4230	186
30	8929	98	6423	66	44	1	318	62	4045	182
40	8831	97	6489	65	43	1	380	61	3863	180
50	8734	98	6554	65	42	1	441	62	3683	178
26 0	$\bar{3}$·9958636	102	$\bar{1}$·9976619	68	$\bar{8}$·38041	1	0·34503	63	0·13506	175
10	8534	100	6687	67	40	1	566	63	3330	174
20	8434	101	6754	67	39	1	629	63	3156	171
30	8333	99	6821	66	38	1	692	64	2985	170
40	8234	102	6887	68	37	1	756	64	2815	166
50	8132	102	6955	68	36	1	820	65	2649	167

Table exhibiting the Logarithmic values of P, Q, R, S, and T, between the parallels of 18° and 35° of Latitude.—(Continued.)

λ	P	Diff.	Q	Diff.	R	Diff.	S	Diff.	T	Diff.
27° 0′	3·9958030	−101	1·9977023	+67	8·38035	−1	0·34885	+65	0·12482	−163
10	7929	103	7090	69	34	1	950	66	2319	161
20	7826	103	7159	69	33	1	0·35016	66	2158	160
30	7723	104	7228	69	32	1	082	67	1998	158
40	7619	102	7297	68	31	1	149	67	1840	155
50	7517	106	7365	70	30	1	216	68	1685	154
28 0	3·9957411	104	1·9977435	70	8·38029	1	0·35284	68	0·11531	152
10	7307	105	7505	70	28	1	352	68	1379	150
20	7202	107	7575	71	27	2	420	70	1229	149
30	7095	105	7646	70	25	1	490	69	1080	147
40	6990	106	7716	71	24	1	559	70	0933	144
50	6884	106	7787	70	23	1		71	0·789296	144
29 0	3·9956778	107	1·9977857	72	8·38022	1	0·35700	71	0·10645	141
10	6671	107	7929	71	21	1	771	71	0504	140
20	6564	109	8000	73	20	1	842	72	0364	138
30	6455	108	8073	72	19	1	914	72	0226	136
40	6347	109	8145	73	18	1	986	73	0 10090	135
50	6238	110	8218	73	17	1	0·36059	74	0·09955	133
30 0	3·9956128	108	1·9978291	72	8·38016	1	0·36133	74	0·09822	132
10	6020	109	8363	73	15	1	207	74	9690	130
20	5911	110	8436	73	14	1	281	75	9560	129
30	5801	110	8509	73	13	2	356	75	9431	127
40	5691	111	8582	74	11	1	431	76	9304	125
50	5580	112	8656	75	10	1	507	77	9179	124
31 0	3·9955468	110	1·9978731	73	8·38009	1	0·36584	77	0·09055	122
10	5358	113	8804	76	08	1	661	77	8933	121
20	5245	111	8880	74	07	1	738	78	8812	120
30	5134	113	8954	75	06	1	816	78	8692	119
40	5021	112	9029	75	05	1	894	79	8573	116
50	4909	113	9104	75	04	2	973	80	8457	115
32 0	3·9954796	114	1 9979179	76	8·38002	1	0·37053	80	0·08342	114
10	4682	114	9255	75	01	1	133	80	8228	113
20	4568	114	9330	76	00	1	213	81	8115	111
30	4454	114	9406	77	8 37999	1	294	82	8004	110
40	4340	115	9483	76	98	1	376	82	7894	108
50	4225	115	9559	77	97	1	458	82	7786	107
33 0	3·9954110		1·9979636	77	8 37996	2	0·37540	83	0·07679	106
10	3995	115	9713	77	94	1	623	84	7573	105
20	3879	116	9790	77	93	1	707	84	7468	104
30	3764	115	9867	77	92	1	791	85	7364	102
40	3647	117	9944	78	91	1	876	85	7262	101
50	3531	116	1·9980022	78	90	1	961	86	7161	99
34 0	3·9953414	117	1·9980100		8·37989	2	0·38047	86	0·07062	99
10	3297	117	0178	78	87	1	133	87	6963	97
20	3180	117	0256	78	86	1	220	87	6866	96
30	3062	118	0334	78	85	1	307	88	6770	95
40	2945	117	0413	79	84	1	395	88	6675	94
50	2827	118	0492	79	83	1	483	89	6581	93
35 0	3·9952708	119	1·9980571	79	8·37982		0 38572		0·06488	

CHAPTER VI.

The Computation of Heights.

To compute the difference of height between two Trigonometrical Stations, the elements required are derived partly from observation, and partly from previous computation. Of the former class, are the vertical angles taken at one or both the stations, and the heights of the instrument and of the signals used. Of the latter class, are the distance at the sea level between the two stations, and the elevation of one of those stations above the same level.

The observation of a vertical angle is thus made: the theodolite being placed over the centre of the eye station and properly levelled, an intersection is taken to the signal at the object station. The micrometers or verniers to the vertical circle, are now read off: the mean whereof constitutes one observation on one face. The telescope is now turned round 180° vertically as well as horizontally, and the same signal is intersected a second time. The vertical limb being then read off as before, we have the second observation on the opposite face. The mean of the two observations made on reversed faces will furnish, cleared of index and collimation error, the elevation or the depression at which the signal stands, as seen from the eye station.

When a vertical angle is observed, the time of the observation as well as the heights of the instrument and of the signal are noted in the Vertical Angle Book, a specimen of which is subjoined.

By way of distinction the station whose height is given may be called the station *A*, the other whose altitude is required being styled the station *B*. It is also necessary to premise at this place that in the phraseology of the Trigonometrical Survey, the distances at the sea level, such as those derived from a Trigonometrical operation, are called geodetic distances.

Certain preliminary considerations must now be attended to before the computation of height can be taken in hand. In the first place, the given geodetic distance will require to be converted into seconds. When this operation is performed, the resulting element is called the contained arc. The precept for making this deduction is as follows:—Add together

SPECIMEN OF THE VERTICAL ANGLE BOOK.

Afternoon Vertical Angles taken at Shevalingapah Hill Station 1st November, 1838.

Names of Places Observed.	Face.	Time of Observation.	Micrometer Readings. A	Micrometer Readings. B	Mean Vertical Readings. One Face.	Mean Vertical Readings. Both Faces.	Mean Vertical Readings. General.	Remarks.
		h. m.	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	
Yemshaw Hel.	R	5·49	D0 15 29·5	D0 15 21·0	D 0 15 25·25	D 0 15 25·40	D 0 15 25·24	Height of Instrument 62·4 Inches.
	L	5·52	D0 15 27·0	D0 15 24·1	D 0 15 25 55			
	L	5·55	D0 15 25·3	D0 15 23·9	D 0 15 24·60			Height of Heliotrope 22·8 Inches.
	R	5·58	D0 15 29·9	D0 15 21·2	D 0 15 25 55	D 0 15 25·08		

Afternoon Vertical Angles taken at Yemshaw Hill Station, 7th November, 1838.

Names of Places Observed.	Face.	Time of Observation.	Micrometer Readings. A	Micrometer Readings. B	Mean Vertical Readings. One Face.	Mean Vertical Readings. Both Faces.	Mean Vertical Readings. General.	Remarks.
Shevalingapah Hel....	R	5·58	D 0 4 24·4	D 0 4 12·2	D 0 4 18·30	D 0 4 16·75	D 0 4 13·78	Height of Instrument 62·8 Inches.
	L	6· 1	D 0 4 11·4	D 0 4 19·0	D 0 4 15·20			
	L	6· 3	D 0 4 10·8	D 0 4 16·3	D 0 4 13 55			Height of Heliotrope 19·5 Inches.
	R	6· 5	D 0 4 16·1	D 0 4 0·0	D 0 4 8·05	D 0 4 10·80		

NOTE.—All modern Theodolites are provided with Spirit Levels, whereby corrections for Level Error are obtained—See Appendix, "Instructions for Topographical Surveying;" Appendices, "Rules for determining the Value of a Level Scale," "Correcting Vertical Angles for Level Error," and Form for Vertical Angles, Examples 1st and 2nd.

the logarithm of the geodetic distance in feet, and the constant logarithm 3·9935154, the natural number answering to the sum, is the contained arc in seconds.

EXAMPLE.

Take the distance from Yemshaw to Shevalingapah, page 491.

Logarithm of the distance in feet		5·1346620
Constant Log.		$\bar{3}$·9935154
(1) Contained Arc = 1343″	Log.	3·1281774

Again the geodetic distance, as it stands, cannot be employed in the computation of height; it will require to be reduced to the level of station *A*. The formula given at page 470-1 could be easily altered to furnish this result, but as the logarithm of the distance is made use of in the computation, it is obviously more convenient to correct that term at once, which may be effected in the following manner:—

To the logarithm of the height in feet of station *A* above the sea level, add the constant logarithm $\bar{8}$·3168746, the natural number answering to the sum, carried to seven places of decimals, is the logarithmic correction required.

EXAMPLE.

Height of Yemshaw above the sea level. 1463·3 feet,	Log., 3·1653334
	Constant Log., $\bar{8}$·3168746
(1) Logarithmic correction, 0·0000304..............................	Log., $\bar{5}$·4822080

The logarithmic correction added to the logarithm of geodetic distance, gives the logarithm of the distance at the level of station *A*.

Thus $\left.\begin{array}{r} 5·1346620 \\ +\ 0·0000304 \end{array}\right\} = 5·1346924 \left\{\begin{array}{l}\text{Log. of the distance from Yemshaw to She-} \\ \text{valingapah at the level of the former.}\end{array}\right.$

Again, that the computed height of a station may be available for any required use in future, it is necessary to refer that element to a permanent mark belonging to the station. In the Great Trigonometrical Survey of India, the upper station dot is taken as the point of reference. But the instrument with which the vertical angle is taken, as well as the signal observed, being elevated above that dot, it follows that the observed angle will stand in need of two corrections, of which the one arising from the height of the instrument or eye, is called the *eye* correction, while the other proceeding from the elevation of the signal or object observed, is styled the *object* correction.

(1) Both these quantities may now be found by inspection from the G. T. Survey Auxiliary Tables IV* & V*.

The rules by which the corrections above mentioned may be computed are as follow: *

To compute the eye correction.—Add together the logarithm of the height of the *eye* in inches, the arithmetical complement of the logarithm of the distance in feet at the level of station *A*, and the constant logarithm 4·2352439, the natural number answering to the sum is the correction in seconds, additive to an elevation, and subtractive from a depression.

EXAMPLE.

Height of the instrument at Shevalingapah, 62·4 inches,	... Log.,	1·7951846
A. C. of Log. of distance at the level of Yemshaw ...	...	4·8653076
Constant Log.	...	4·2352439
Eye correction, — 7″·87...	... Log.,	0·8957361

To compute the object correction.—Add together the logarithm of the height of the *object* in inches, the arithmetical complement of the logarithm of the distance in feet at the level of station *A*, and the constant logarithm 4·2352439, the natural number answering to the sum is the correction in seconds, additive to a depression, and subtractive from an elevation.

EXAMPLE.

Height of the signal at Yemshaw, 22·8 inches	... Log.,	1·3579348
A. C. of Log. of distance at the level of Yemshaw ...	...	4·8653076
Constant Log.	...	4·2352439
Object correction +2·87	... Log.,	0·4584863

When the observed vertical angle has received the eye and object corrections, the points to which it becomes referrible are the upper station dots. The vertical angle so reduced is called the Apparent Vertical Arc.

EXAMPLE.

		°	′	″
Observed Vertical Angle at Shevalingapah	*D*	0	15	25·24
Eye correction	—			7·87
Object correction	+			2·87
Apparent Vertical Arc at Shevalingapah	*D*	0	15	20·24

The problem of the computation of heights may be divided into the two following cases:—first, when vertical angles have been observed at the two stations *A* and *B*; and secondly, when a vertical angle has been

* The shorter computation is now adopted of correcting for the *difference* between the heights of the eye and object.

taken at one of the stations only. We will now proceed to treat of the first case.

After the observed vertical angles at the two stations *A* and *B* have been reduced into apparent vertical arcs, an auxiliary angle, called the subtended angle, will next require to be computed, which is done in this way. When both the apparent arcs are depressions, take half the difference: when one only is an elevation, take half the sum: the result in either case is the subtended angle required.

EXAMPLE.

		°	′	″
Apparent Vertical Arc at Shevalingapah	*D*	0	15	20·24
Ditto ditto at Yemshaw	*D*	0	4	8·32
Subtended angle		0	5	36·0

By the aid of the subtended angle, derived as directed above, the difference of height between the two stations is easily deducible in the following manner. To the logarithmic sine of the subtended angle, add the log. secant of the vertical arc taken at station *B*, and the logarithm of the distance at the level of station *A*; the natural number answering to the sum is the required difference of height between the two stations.

EXAMPLE.

		°	′	″		
Subtended Angle		0	5	36	Log. Sin.,	7·2119140
Apparent Vertical Arc at Shèvalingapah	*D*	0	15	20	Log. Sec.,	0·0000043
Distance in feet at the level of *Yemshaw*					Log.,	5·1346924
Required difference of height in feet, 222·1					Log.,	2·3466107

Connected with the computation of heights is the important subject of terrestrial refraction; it is evident that every vertical angle observed is affected with that inequality. Its general effect is to raise an object above its true position; when two observed vertical angles are made use of in the computation of a height, although these angles are individually impregnated with refraction, they produce a result which is entirely free from that inequality. This arises from the peculiar combination of the observed vertical angles in the deduction of the subtended angle, whereby the refraction in one angle is cancelled by that in the other.

There is, however, only one condition required to produce this cancelment, namely, an equality of the amounts of refraction in the two observed vertical angles. That this equality may obtain in practice, vertical angle observations at the reciprocal stations should be made under, as nearly as possible, the same atmospheric conditions. When two observers and two instruments are available, they are best taken simultaneously, but in cases

in which this cannot be resorted to, the observations ought to be made contemporaneously, that is, at the same time on different days, these days being separated by as small an interval as possible.

Experience has shewn that the best time for observing a set of vertical angles is between the hours of $2\frac{3}{4}$ and $3\frac{3}{4}$ from apparent noon. When vertical angles have been taken with due regard to the conditions above specified, the precepts, whereby the amount of refraction involved in them may be computed, are as follows:

Take the sum of the reciprocal apparent vertical arcs when they are both depressions, or their difference when one is an elevation, subtract the sum or difference so derived from the contained arc, half the remainder is the amount of terrestrial refraction required

EXAMPLE.

Apparent Vertical Arc at Shevalingapah ...	*D* 0°	15′	20″·24
Ditto ditto at Yemshaw	*D* 0	4	8·32
Which being both depressions are added together, and their sum in seconds is	1169		
Contained arc in seconds	1343		
Half the difference or terrestrial refraction ...	87		

It is a practice with the geodetic writers to express the refraction in decimals of the contained arc: this reduction may be performed as follows:

Reduce the terrestrial refraction and the contained arc to seconds, divide the former by the latter, the quotient is the value of the terrestrial refraction in decimals of the contained arc.

EXAMPLE.

Thus in the case of Yemshaw and Shevalingapah, the refraction being 87″, and the contained arc 1343″, we shall have $\frac{87}{1343}'' = \cdot065$, for the value of the refraction in decimals of the contained arc.

It now remains to explain Case 2nd, or the method of computing the difference of heights between two stations from a vertical angle taken at one of them only. The observed vertical angle being corrected for the heights of the instrument and signal, as well as for refration,* we shall have the value of the vertical angle, as if it were taken in vacuo at the station of observation.

* There are no fixed rules for Terrestrial refraction, but it is generally taken at one-fifteenth of the contained arc; in determining the heights of the peaks of the Snowy Range (Himalayas), about one-thirteenth of the contained arc was assumed.

Now the contained arc is equal to the sum of the two vertical angles in vacuo, when they are both depressions, or to the difference between them when one is an elevation, which relation gives the following simple precepts for computing the vertical angle in vacuo, at the object station. When the vertical angle in vacuo at the eye station is a depression, take the difference between it and the contained arc; when it is an elevation, take their sum; the resulting element in either case is the vertical angle in vacuo at the object station.

To determine whether the last deduced vertical angle is an elevation or a depression, the considerations which will require to be attended to are three in number, and they are as follow:—

First, when the vertical angle in vacuo at the eye station is a depression, and less than the contained arc; *second,* when it is a depression and greater than the contained arc; and *third,* when it is an elevation.

In the first and third cases, the resulting vertical angle at the object station is a depression, and in the second, it is an elevation.

Having obtained the two vertical angles in vacuo, treat them as if they were apparent vertical arcs, and deduce therefrom the subtended angle, and the difference of height, as in Case 1st. To exemplify this computation, take the deduction of Himalaya snowy peak α from Amsot Hill station:

		°	′	″
Observed vertical angle at Amsot	*E*	2	20	45·93
Eye correction			+	3·12
Object correction is evanescent, the top of the peak being observed			...	0·00
Refraction taken at $\frac{1}{15}$th of contained arc			— 3	49·26
Vertical angle in vacuo at Amsot	*E*	2	16	59·79
Which being an elevation, will require to be augmented by the contained arc	+	0	57	18·90
Vertical angle in vacuo at snowy peak α	*D*	3	14	18·69

FORM FOR REGISTERING THE COMPUTATION OF THE HEIGHT OF A TRIGONOMETRICAL STATION.

Shevalingapah deduced from Yemshaw. *Height of Yemshaw above the sea level* = 1463·3 *feet.*

D. Day Observation. N. Night Observation.	Eye Stations.	Object Stations.	Observed Vertical Angles.	Log. of the Geodetic Distances.	Logarithmic Correction Additive.	Contained Arc.	Object Corrections. Inches.	Object Corrections. Angle.	Eye Corrections. Inches.	Eye Corrections. Angle.	Apparent Vertical Arc.	Terrestrial Refraction. Seconds.	Terrestrial Refraction. Decimal of contained Arc.	Subtended Angle.	Heights Deduced. Comparative.	Heights Deduced. Above the Sea Level.
D	Sheva-lingapah..	Yemshaw	D 0° 15′ 25″ 24	......	....	....	22·8	+2 87	62·4	−7·87	D 0° 15′ 20″·24					
				5·1346620	304	1343						87	·065	0° 5′ 36″·0	+222·1	Shevalingapah 1685·4 feet.
	Yemshaw	Shevalinga-pah ..	D 0 4 13·78	.....	....	....	19·5	+2·46	62·8	−7 92	D 0 4 8·32					

Himalaya Snowy Peak a deduced from Amsot Hill Station. *Height of Amsot above the sea level* = 2352·3 *feet.*

D. Day Observation. N. Night Observation.	Eye Stations.	Object Stations.	Observed Vertical Angles.	Log. of the Geodetic Distances.	Logarithmic Correction Additive.	Contained Arc.	Object Corrections. Inches.	Object Corrections. Angle.	Eye Corrections. Inches.	Eye Corrections. Angle.	Apparent Vertical Arc.	Terrestrial Refraction. Seconds.	Terrestrial Refraction. Decimal of contained Arc.	Subtended Angle.	Heights Deduced. Comparative.	Heights Deduced. Above the Sea Level.
D	Snowy peak *a*	Amsot,	....	....	..	..	..	..	..	..	D 3 14 18·69					
												−229 26	..	2 45 39 2	+16842·8	Snowy Peak *a* 20095·1 feet.
	Amsot,	Snowy peak *a*	E 2·20 45·93	5·5429020	675	3438·9	..	..	63 3	+3·12	E 2 20 49·05					

CHAPTER VII.

MINOR TRIANGULATION, AND THE SAME AS APPLIED TO THE RAY TRACE SYSTEM, FOR CARRYING ON TOPOGRAPHICAL SURVEYS.*

AFTER having explained the approved principles of observation and computation, as generally practised in a Trigonometrical Survey, we will now proceed to shew their application to the detail survey of a district.

The primary triangles of a Topographical Survey may be thrown into the form of a network as shewn in Plate 17, Fig. 1, or into that of a gridiron exhibited in Fig. 2. Of these two forms the gridiron is preferable to the network: in the first place, because it contains a smaller number of triangles, and is more scientific; and secondly, because it is susceptible of a more systematic deduction than the other. This mode of distribution, however, will be found more difficult in most hilly countries than the common network, and occupy a longer time than is generally allotted to Topographical Surveyors, but whatever form may be given to the primary triangles of a Topographical Survey, there is one condition,—namely, that of symmetry,—which ought to be strictly adhered to in their selection. In no case should a triangle of a primary character be admitted, any of whose angles falls short of 30° or exceeds 90° as before stated at page 472.

The sides of these primary triangles should average between two and five miles, and the best instrument for executing this description of work is a 12 or 14-inch Theodolite. The three angles of a primary triangle ought, in every instance, to be observed, every angle being measured on two zeros 0° and 30° with their reversed faces, as before described. As to computation, those triangles may be treated as *plane*, the spherical excess being in their case an unappreciable quantity, the angles used being taken to the nearest second.

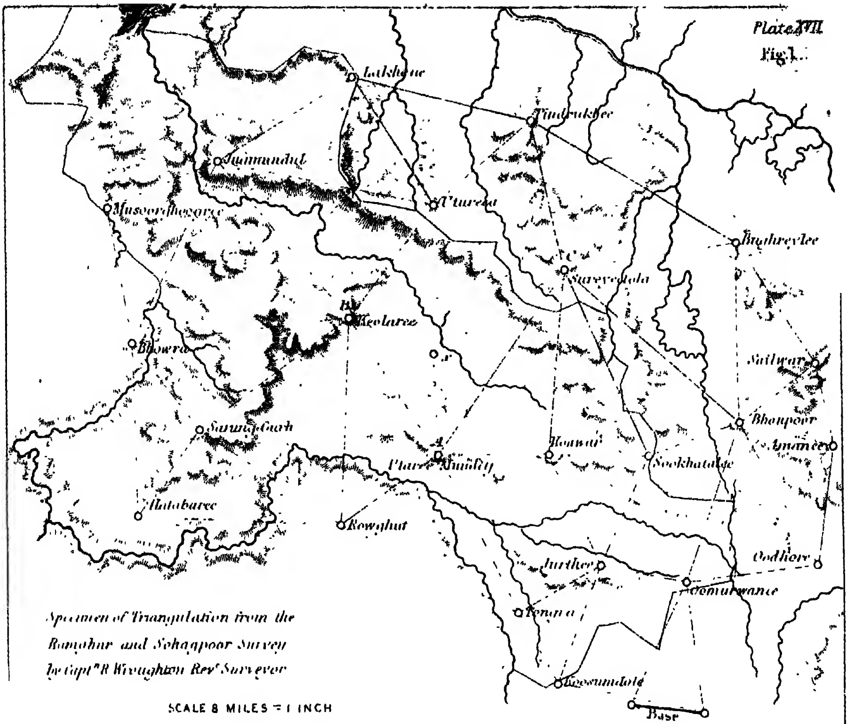
With due regard to these precautions, the primary triangulation of a district being executed, the next thing to be taken in hand is the collection of the Topographical details, which may be done in the following manner:—

If the point x (Plate 17), which we shall suppose to be the site of a village, be observed from two primary stations A and B, we shall have the triangle ABx giving the position of the last mentioned point. Again, if x happen to be observed from three primary stations, as A, B, and C, the

* See Instructions for Topographical Surveys in India, by Colonel Waugh, late Surveyor-General of India, printed in 1855, given in the Appendix.

Plate XVII

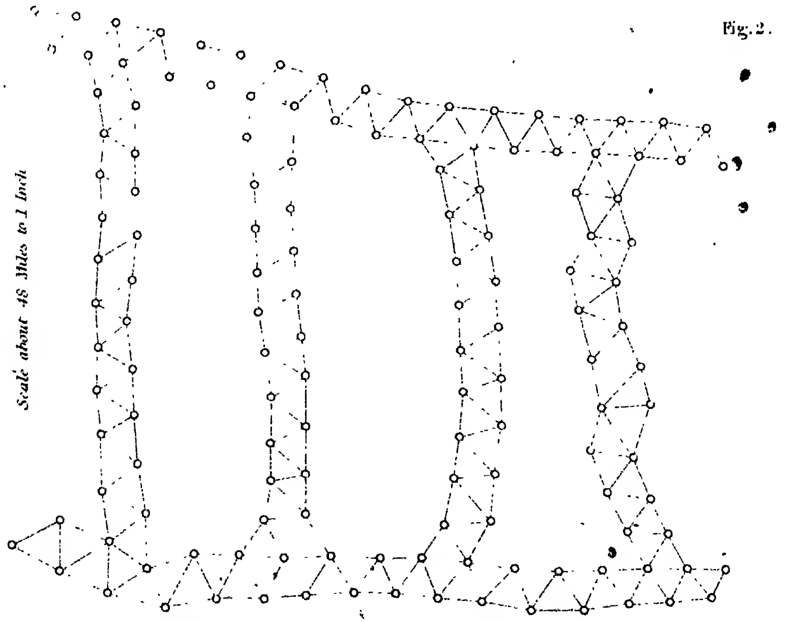
Fig. 1.



Specimen of Triangulation from the Ramghur and Sohagpoor Survey by Capt.ⁿ R. Wroughton Rev.ᵉ Surveyor

SCALE 8 MILES = 1 INCH

Fig. 2.



Scale about 48 Miles to 1 Inch

triangles formed will be three in number,—namely, 1st, $\triangle$ *A Bx*; 2nd, $\triangle$ *A Cx*; and 3rd, $\triangle$ *BCx*. Now, here are three distances, *Ax*, *Bx*, and *Cx*, which are respectively possessed of two values, the first being derived from $\triangle$s 1 and 2, the second from $\triangle$s 1 and 3, and the third from $\triangle$s 2 and 3. These double values being compared, the discrepancies (if any) will indicate the amount of confidence to be attached to the result.

The point *x* fixed in the way described above is called an intersected point. For the reasons already stated, a point of this kind should be determined, whenever it is practicable, by two triangles possessing a common side.

In the case of the intersected points, the symmetry of the triangles cannot be so rigorously attended to as in the instance of the primary stations, because such points must be observed from wherever they are visible. Here, however, a small error in a given position would be attended with no inconvenience, as it would not extend beyond the site to which it appertains. It has been found in practice, that triangles whose angles range between 15° and 150° furnish trustworthy results. The angles to intersected points should be observed on zero 0° and on its reversed face, the observation in each case being repeated twice to check the readings of the instrument as well as the record thereof, and the same object should be intersected from three or more stations to verify the position of the intersected point.

Some attention must be paid to the signals used: if they are large undefined objects, as whole bodies of villages, &c., they will be unsusceptible of accurate intersection, and will therefore produce discordant results. The *kalus* of a mosque, or of a temple, church spire, tops of columns, &c., form good objects for intersection, but these are seldom to be met with, and in their absence flags may be used, which may either be placed on the ground, or fastened to tops of high trees, as may be convenient. Tree flags have been tried in the Great Trigonometrical Survey, and found to answer well.

It is clear that most of the villages in a district, as well as all the prominent marks on the boundary line, could be laid down as intersected points: the few villages that cannot be so determined may be fixed by a measured angle and distance from a primary station. The sides of the secondary triangles should be carried as near the boundary of the subdivision or pergunnah circuits as possible, in cases where a Revenue Survey is required, but this of course will depend on the natural features of the country. On any of the sides of these, the Plane Table and Cross Staff is applied, and the intervals are filled up by sketching, and a series of perpendicular lines are thus made to traverse the Topographical

details. The more minutely the triangulation has been carried on, the easier and more correct will be the interior filling up, whether entirely by measurement with the Chain, or only partially so, and the remainder completed by sketching. The Plane Table is the best contrivance for this purpose, and the process of sketching between the fixed points plotted on the paper, is similar to surveying with the Chain and Theodolite as far as the natural and artificial boundaries* are concerned. Every thing being at once drawn on the paper instead of being entered in a Field Book, the features of the ground are sketched at the same time as the boundaries and other details. This part of the operation, however, requires much practice before anything like facility of execution can be acquired.

The Plane Table is made in a variety of ways, but to render it really useful, it should be reduced to the most simple state possible, and as light as can be consistent with strength and steadiness. The English manufacture with the box-wood scale frame, as described at page 54, is quite unsuited to the heat and hot winds of this climate; they warp, and go to pieces immediately; but the pattern now in use, as made up in the Mathematical Instrument Department, Calcutta, of the best seasoned *teak* wood, or English *deal*, is a simple square board, without any shifting frame, with the fiducial edge ruler of ebony, the brass Sights being affixed at each end, the Table fixing on the braced tripod stand, by means of a clamping screw under it.†

Every two points of a Survey, whatever objects may be between them, will in fact be the extremities of a base equally true as if it had been actually measured; and the Table being placed on such points, and adjusted by means of the legs, and the needle, which answers instead of a level, where the greatest accuracy in fixing the instrument horizontally is not required, we obtain intersections to all objects of which it may be necessary to find the place. This is done by placing a pin or the leg of a pair of compasses upon the station point, and the edge of the ruler in contact with it, turning the ruler as upon a pivot, until the object to be intersected is seen along its edge, and then drawing a fine line by the same edge. This being done from three different places, will be found very exact in most cases, although there is in strictness an error of the same kind as that mentioned in treating of the Theodolite, when it is not exactly over a station; but this nicety is of little consequence, for the Table, being but small, the difference occasioned by the eccentricity of the instrument

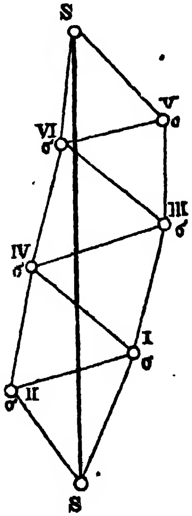
* Boundaries, roads, railways, large streams and rivers, should always be carefully traversed along their entire course, with the Plane Table and Chain, or Perambulator, and every salient point on a boundary should be a Plane Table Station.

† See Appendix—Instructions on Topographical Surveying.

can never make any appreciable error in the position of an object, and upon almost all scales in common use, this magnitude is but a mere point. Thus we may join up any unfinished lines that were left in surveying to avoid short stations, or for other reasons.

When the method of surveying the interior details is rigidly carried out, there is nothing left to be sketched in, except the contours of the ground which do not present marked features to which measurement can be applied. The comparative heights however, obtained by levelling with the Theödolite during the Survey, present so many certain points of reference as to the relative command of the ground, and are of course of the greatest assistance in the subsequent delineation of the features upon the outline plan. When the inequalities of the surface of any particular portions require to be shewn more in detail, recourse must be had to a regular process of Levelling and Contouring, both of which subjects are treated of hereafter in separate Chapters.

With a view of adapting the triangulation of a district convenient for this purpose, suppose a series of principal triangles of the Great Trigonometrical Survey to have been carried through a district, it is evident that the sides of those triangles, ranging from ten to twenty miles, cannot, as they stand, be immediately made use of in a Topographical Survey, in which bases of two to five miles only are required. To resolve therefore a side of a principal triangle into a convenient number of small distances of the required lengths, the Ray Trace System by minor triangulation may be resorted to with great advantage. We will now proceed to explain the method.



Let S and S' be two stations of the Trigonometrical Survey. Taking S as an origin, select a series of small triangles along the given line SS' until the other extremity S' is reached and is connected therewith; these triangles must be treated as primary triangles of a detail operation. Their computation may be performed as follows: on reference to the diagram it will be seen that there are two lines $S\sigma'$ and $S\sigma''$ connected with the origin S, assuming either of these as unity, the remaining sides of the triangulation may be deduced in terms thereof.

It is evident that if the whole distance SS' can be obtained in terms of the same measure, the deduction of the true values of the sides of minor

triangulation may be easily effected by the following rules of proportion:

As the hypothetical value of the line SS' (ρ).

: The true trigonometrical value thereof (R).

:: The hypothetical value of the side,

: Its corresponding trigonometrical length.

To determine the hypothetical value of the side SS', the method of computation explained at pp. 456 to 459 will require to be resorted to. Take the series of sites on the right or left flank of the minor triangulation as may be convenient, and consider them as the stations of a Route Survey. The elements which will be required for the deduction of either of the flanking lines, taken as a route, are the distances and angles.

The distances to be used are the hypothetical distances derived, as described above, on the assumption of one of the two first sides of the minor triangulation taken as unity.

The angle at any site of the minor triangulation taken as a Route Survey Point, is determined in this way. Suppose an observer to be placed at the given site looking in the direction of the rear Station, let him turn round towards his right until he faces the point in advance; the horizontal arc which his eye will describe during this operation is that which will be required in the Ray Trace deduction. A reference to the sketch of the minor triangulation will indicate the process of deriving the arc from the angles of the primary triangles. The only circumstance to be attended to in this computation is, that the angles used must be those which have been adjusted to 180°.

Computing the arcs above mentioned for the several sites on the right or left flank (as the case may be) of the minor triangulation, and calling them in the order in which they stand $\angle$s $\odot^1$, $\odot^2$, $\odot^3$ .... of the Route Survey, deduce therefrom the angles for computation A, B, C ...... as detailed in Chapter 2nd, pp. 457-8.

With these angles for computation and the hypothetical distances, the co-ordinates x' x'' x''' .... and also y', y'', y''', ... being deduced, the whole line SS' may be derived in terms of the first side of the minor triangulation.

The hypothetical value of the line SS' being determined and its true value having been previously derived from the Trigonometrical Survey, the true lengths of the sides of the minor triangulation can be ascertained by the rule of proportion given before.

The angels θ and θ_1 of p. 350 derived from this computation, are useful in determining the azimuths of the first and last sides of the minor triangulation. For instance, the azimuth of the line $Ss' = A - \theta$, A being

the azimuth of S' from S. Similarly, calling B the back azimuth of S from S', the azimuth of the last line will be $B - \theta'$. With these azimuths, the geographical position of S and S' being given, the latitudes and longitudes of the stations of the minor triangulation may be deduced.

To illustrate the computation of a Ray Trace by minor triangulation, take the following example from the Report of the Great Trigonometrical Survey of India.

Tracing of Ray Dahera to Nojhili by Minor Triangulation, executed by Babu Radhanath Sickhdar, Sub-Assistant Great Trigonometrical Survey, with a 12-Inch Theodolite of the East India Company's Pattern, in the year 1840.

Names of Stations.	Observed Angles.	Apportionment of Error.	Corrected Angles.	Log. Sines.	Hypothetical Distances.	True Distances in Feet.	True Distances in Miles.
No. 1	Dahera to Rankandi—Hypothetical Dist. Log. 0·0000000. True Dist. in feet Log. 4·0145561.						
Dahera ..	° ′ ″ 65 25 46·8	+ 5·8	65 25 53	9·9587855	1·451905	15013·9	2·844
Rankandi ..	73 17 30 4	+ 5·8	73 17 36	9·9812699	1·378650	14256·4	2·700
Station 3 ..	41 16 25 4	+ 5·8	41 16 31	9·8193316	Logs. 0·1619383 0·1394539	Logs. 4·1764944 4·1540100	
	179 59 42·6	+17·4	180 0 0				
2	Dahera to Station 3—Hypothetical Dist. Log. 0.1619383. True Dist. in feet Log. 4·1764944.						
Dahera ..	68 18 43·8	— 3·8	68 18 40	9·9681112	1 806980	18685·7	3·539
Station 3 ..	64 58 7·6	— 3·8	64 58 4	9·9571617	1·853118	10162·8	3·629
Barheri ..	46 43 19·9	— 3·7	46 43 16	9·8621465	Logs 0·2569535 0·2679030	Logs. 4·2715096 4·2824591	
	180 0 11·3	—11·3	180 0 0				
3	Barheri to Station 3—Hypothetical Dist. Log. 0·2679030. True Dist. in feet Log. 4·2824591.						
Barheri ..	57 40 36·4	+ 2·1	57 40 38	9·9268821	1·708709	17669·5	3·346
Station 3 ..	56 56 58·8	+ 2·0	56 57 1	9 9233164	1·722677	17813·9	3·374
Labkari ..	65 22 18·6	+ 2·1	65 22 21	9·9585814	Logs. 0·2326682 0·2362039	Logs. 4·2472243 4·2507600	
	179 59 53·8	+ 6·2	180 0 0				
4	Barheri to Labkari—Hypothetical Dist. Log. 0·2326682. True Dist. in feet Log. 4·2472243.						
Barheri ..	65 36 13·6	— 2·7	65 36 11	9·9593781	1·966310	20333 3	3·851
Labkari ..	63 24 22·3	— 2·6	63 24 20	9·9514335	2·00261[illegible]	20708 7	3·922
Station 4 ..	50 59 32·0	— 2·6	50 59 29	9·8904497	Logs 0·2936520 0·3015966	Logs. 4·3082081 4 3161527	
	180 0 7·9	— 7·9	180 0 0				
5	Labkari to Station 4—Hypothetical Dist. Log. 0·3015966 True Dist. in feet Log. 4 3161527.						
Labkari ..	51 6 9·6	+ 2·9	51 6 12	9·8911357	1·852150	1915[illegible]·8	3·627
Station 4 ..	59 46 47·8	+ 2·9	59 46 51	9·9365673	1·668186	17250·5	3·267
Paka Well ..	69 6 53·8	+ 3·0	69 6 57	9·9704878	Logs. 0·2676761 0·2222445	Logs. 4·2822322 4·2368006	
	179 59 51·2	+ 8·8	182 0 0				

Names of Stations.	Observed Angles.	Apportionment of Error.	Corrected Angles.	Log. Sines.	Hypothetical Distances.	True Distances in Feet.	True Distances in Miles.
6	Station 4 to Paka Well—Hypothetical Dist. Log. 0·2222415.	True Dist. in feet Log. 4·2368006.					
	° ′ ″						
Station 4 ..	59 41 44·1	+ 0·3	59 41 44	9·9361901	1·572081	16256·7	3·079
Paka Well ..	57 11 35'5	+ 0·2	57 11 36	9·9245396	1·614826	16698·7	3·163
					Logs.	Logs.	
Pirer ..	63 6 39·6	+ 0·3	63 6 40	9·9503090	0·1964751	4·2110312	
					0·2081256	4·2226817	
	179 59 59·2	+ 0·8	180 0 0.				
7	Paka Well to Pirer—Hypothetical Dist. Log. 0·2081256.	True Dist. in feet Log. 4·2226817.					
Paka Well ..	51 7 33·4	+ 0·3	51 7 34	9·8912749	1·819305	18813·2	3·563
Pirer ..	71 31 58·1	+ 0·3	71 31 58	9·9770396	1·493279	15441·8	2·925
					Logs.	Logs.	
Paniari ..	57 20 27·6	+ 0 3	57 20 28	9·9252596	0·2599056	4·2744617	
					0·1741409	4·1886970	
	179 59 59·1	+ 0·9	180 0 0				
No. 8	Pirer to Paniari—Hypothetical Dist. Log. 0·1741409.	True Dist. in feet Log. 4·1886970.					
Pirer ..	53 26 57·5	+ 1·4	53 26 59	9·9048965	1·686672	17441·6	3·303
Paniari ..	70 9 44·0	+ 1·5	70 9 45	9·9734322	1·440439	14895·4	2·821
					Logs.	Logs.	
Mirpur ..	56 23 14·2	+ 1·4	56 23 16	9·9205424	0·2270307	4·2415868	
					0·1584950	4·1730511	
	179 59 55·7	+ 4·3	180 0 0				
9	Paniari to Mirpur—Hypothetical Dist. Log. 0·1584950.	True Dist. in feet Log. 4·1730511.					
Paniari ..	65 24 22·5	+ 2·0	65 24 24	9·9586998	1·546149	15988 5	3·028
Mirpur ..	60 27 4·7	+ 2·0	60 27 7	9·9394905	1·616071	16711·5	3·165
					Logs.	Logs.	
Station 5 ..	54 8 26·8	+ 2·0	54 8 29	9·9087343	0·1892512	4 2038073	
					0·2084605	4·2230166	
	179 69 54·0	+ 6·0	180 0 0				
10	Mirpur to Station 5—Hypothetical Dist. Log. 0 2084605.	True Dist. in feet Log. 4·2230166.					
Mirpur ..	69 43 45·7	+ 1·9	69 43 48	9·9722355	2·091916	21632·2	4·097
Station 5 ..	65 34 16·3	+ 1·8	65 34 18	9·9592701	2·155310	22287·7	4·221
					Logs.	Logs.	
Subri ..	44 41 52·5	+ 1·8	44 41 54	9·8471863	0·3205443	4 3351004	
					0·3335097	4·3480658	
	179 59 54·5	+ 4·5	180 0 0				
*11	Station 5 to Subri—Hypothetical Dist. Log. 0·3335097.	True Dist. in feet Log. 4·3480658.					
Station 5 ..	56 59 19·4	+ 4·9	56 59 24	9·9235422	1·621567	16768·4	3·176
Subri ..	46 54 42·0	+ 4·8	46 54 47	9·8635120	1·861938	19254·0	3·647
					Logs.	Logs.	
Nojhili ..	76 5 44·0	+ 4·9	76 5 49	9·9870867	0·2099350	4·2244911	
					0·2699652	4·2845213	
	179 59 45·4	+14·6	180 0 0				

TYPE OF CALCULATION OF RAY DAHERA TO NOJHILI.

Distances.		*Angles.*		
Dahera to Station 3 ...	$a = 1·451905$			° ′ ″
Station 3 to Labkari ...	$a = 1·722677$	At Station 3 ...	$\odot 1 =$	121 55 5
Labkari to Paka Well	$b = 1·852150$	„ Labkari ...	$\odot 2 =$	179 52 58
Paka Well to Paniari...	$c = 1·819305$	„ Paka Well ...	$\odot 3 =$	177 26 7
Paniari to Station 5 ...	$d = 1·546149$	„ Paniari ...	$\odot 4 =$	192 54 37
Station 5 to Nojhili ...	$e = 1·621567$	„ Station 5 ...	$\odot 5 =$	176 42 11

Hence the angles for computation are as follows:

$A = 121°\ 55'\ 5''$
$B = (121°\ 55'\ 5'' + 179°\ 52'\ 53'' - \pi) = 121°\ 47'\ 58''$
$C = (121°\ 47'\ 58'' + 177°\ 26'\ 7'' - \pi) = 119°\ 14'\ 5''$
$D = (119°\ 14'\ 5'' + 192°\ 54'\ 27'' - \pi) = 132°\ 8'\ 42''$
$E = (132°\ 8'\ 42'' + 176°\ 42'\ 11'' - \pi) = 128°\ 50'\ 53''$

A = 121 55 5	Cos. 9·7232141		Sin. 9·9288080	
a = 1·722677	Log. 0·2362039		Log. 0·2362039	
	1·9594180 ...	+ 0·910789	0·1650119 ...	− 1·462217
B = 121 47 58	Cos. 9·7217674		Sin. 9·9293667	
b = 1·852150	Log. 0·2676761		Log. 0·2676761	
	$\bar{1}$·9894435 ...	+ 0·975986	0·1970428 ...	− 1·574138
C = 119 14 5	Cos. 9·6887655		Sin. 9·9408283	
c = 1·819305	Log. 0·2599056		Log. 0·2599056	
	$\bar{1}$·9486711 ...	+ 0·888528	0·2007339 ...	− 1·587574
D = 132 8 42	Cos. 9·8267284		Sin. 9·8700813	
d = 1·546149	Log. 0·1892512		Log. 0·1892512	
	0·0159796 ...	+ 1·037480	0·0593325 ...	− 1·146390
E = 128 50 53	Cos. 9·7974457		Sin. 9·8914827	
e = 1·621567	Log. 0·2099350		Log. 0·2099350	
	0·0073807 ...	+ 1·017140	0·1013677 ...	− 1·262890

a = + 1·451905

Sum of Direct Co-ordinates, x = 6·281828 Sum of Perpr. Co-ordinate y = − 7·033215

Sum of Direct Co-ordinates, x = 6·281828 Log. 0·7980861

A.C. 9·2019139

Sum of Perpr. Co-ordinates, y = 7·033215 Log. 0·8471539

$\theta = -48°\ 13'\ 47''{\cdot}5 \begin{cases} \text{Tan. } 0{\cdot}049067 \\ \text{Sec. } 0{\cdot}1764320 \end{cases}$

Sum of Direct Co-ordinates, x = 6·281828 Log. 0·7980861

Nojhili to Dahera by Ray Trace Computation, Log. 0·9745181
Ditto by Trigonometrical Survey, Log. 4·9890741

Constant Log. of Correction, 4·0145560

This constant logarithm, added to the logarithms of the distances derived from the Ray Trace computation, will furnish the logarithms of the same distances, in terms of the unit of the Trigonometrical Survey.

θ′ Computed.

		°	′	″
	$\pi - \theta =$	131	46	12·5
From which deduct E or last ∠ for Computation		128	50	53·0
	$\theta' =$	2	55	19·5

Deduction of the Azimuths.

		°	′	″
At Dahera, Azimuth of Nojhili	$A =$	190	51	40·9
	$\theta = -$	48	13	47·5
Azimuth of Station 3, $(A-\theta) =$		239	5	28·4
At Nojhili, Azimuth of Dahera	$B =$	10	53	24·5
	$\theta' = +$	2	55	19·5
Azimuth of Station 5, $(B - \theta' =$		7	58	5·0

A sketch of the foregoing Ray Trace, as well as of two others connected therewith, completing a principal triangle of the Great Trigonometrical Survey, is given in plate XVIII. On reference to this sketch it will be perceived that the triangulation originating from Dahera proceeds along the ray to Nojhili, whence it extends in the ray to Godhna, and thence returns and closes in at Dahera.

Each of these Ray Traces being deduced by an independent computation, it is evident that the sides, whereby these operations are connected with one another, will possess double values, which, when compared, will obviously indicate the degree of accuracy attained by the work. There are three sides of this description belonging to the minor triangulation in the sketch, and they are as follow :—

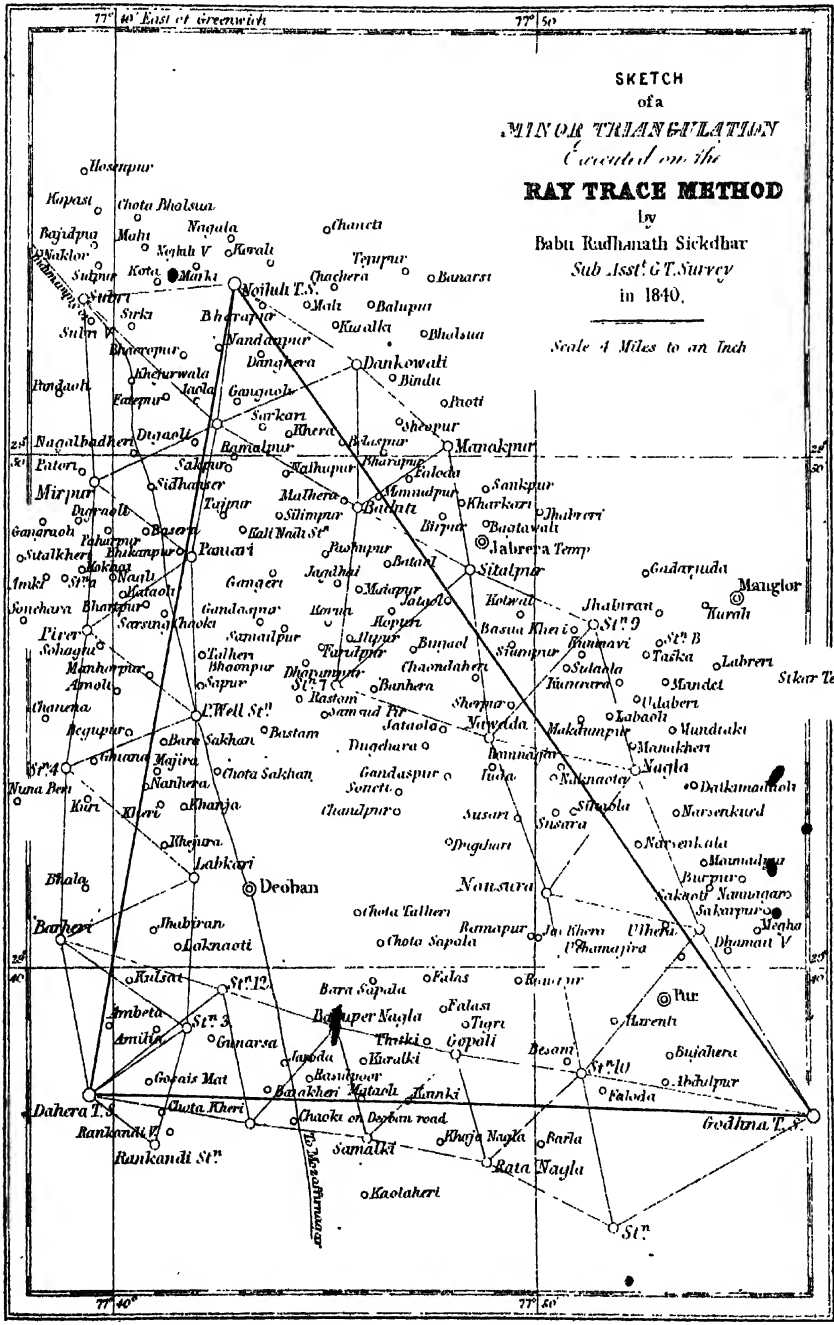
1st Nojhili to Station 5.

Feet.	
16768·4	Derived from Ray Dahera to Nojhili.
16771·0	" " Nojhili to Godhna.
2·6	Error in the Triangulation.

2nd.—Godhna to Station 10.

Feet.	
29034·2	Derived from Ray Nojhili to Godhna.
29034·0	" " Godhna to Dahera.
0·2	Error in the Triangulation.

Plate XVIII.



J W Lowry fc

3rd.—Dahera to Barheri.

Feet.	
18682·6	Derived from Ray Godhna to Dahera.
18685·7	„ „ Dahera to Nojhili.
3·1	Error in the Triangulation.

It will be seen that the primary triangles appertaining to the three Ray Traces are 32 in number. Taken by themselves, they are of no value, as they furnish little or no topographical information; they become valuable, only when they are made the basis for laying down village sites and other geographical points, of which the number determined by the triangulation under consideration is 190, and from the sides of these triangles as bases, any description of Theodolite and Chain, Plane Table, or Compass Surveying, according to the ordinary method, may emanate for the perfection of the general details.

Many of these points are fixed by two, some by three, and a few again by so many as four triangles. The common sides presented by this process never exhibit a discrepancy exceeding a foot per mile.

We will conclude this chapter by giving the computation of a village site fixed by three independent triangles.

No.	Names of Stations.	Intersected Objects.	Angles for Computation.	Log. Sines.	Distances in Feet.	Distances in Miles.
	Paniari to Mirpur = 14895·4 *feet Log.* 4·1730511 *Miles* 2·821 (Δ8.)					
	Paniari .. Mirpur .. Sidhanser ..	Flag on the highest tree in Village.	° ′ ″ 23 16 15 32 40 18 124 3 27 180 0 0	9·5966828 9·7322523 9·9182799	9706 7103 Logs. 3·9870235 3·8514540	1·838 1·345
	Mirpur to Station 5 = 16711·5 *feet Log.* 4·2230166 *Miles* 3·165 (Δ9.)					
	Mirpur .. Station 5 .. Sidhanser ..	Ditto.	27 46 47 17 36 53 134 36 20 180 0 0	9·6684544 9·4808902 9·8524543	7103 10940 Logs. 3·8514525 4·0390167	1·345 2·072
	Station 5 to Paniari = 15988·5 *feet Log.* 4·2038073 *Miles* 3·028 (Δ9.)					
	Station 5 .. Paniari .. Sidhanser ..	Ditto.	36 31 30 42 8 8 101 20 22 180 0 0	9·7746436 9·8266493 9·9914385	10940 9705 Logs. 4·0390181 3·9870124	2·072 1·838

CHAPTER VIII.

THE DETERMINATION OF THE POSITION OF A POINT FROM OBSERVATIONS MADE THEREAT, TO THREE KNOWN STATIONS, AND THE REDUCTION OF ANGLES TO THE CENTRE OF A STATION.

THE problem of fixing a Station by observations to three known points has been extensively used in rough hilly countries, especially by the late Captain Wroughton, in the Sohagpore and Ramghur Territory. The mathematical part of this problem is old enough, but it is not an easy matter to compute. The geometrical construction has already been given at page 65, but as that does not readily suggest a convenient mode of computation, the following formula has been computed for the more rapid deduction of the problem. It is necessary that a Surveyor should have these rules, in case of accident, from having no other data, and from the necessity sometimes to bring up the work of others. As a *system*, however, observations to three points are unsatisfactory and lazy, the method is unsusceptible of minute accuracy, and there is no check; unless four points are observed, large errors may creep in, from mistakes in record, or in mistaking the Stations. The observer has only to go up one of the three known points, and observe back to the Station requiring to be fixed, and the case then becomes an affair of simple triangles checked by common sides, and this should always be done by a careful Surveyor. The Rule is, if a point depends on a single triangle, all three angles should be observed; if only two angles in a triangle can be observed, there should be at least two triangles to give a common side, and thus check the accuracy of the determination, as adverted to at page 508.

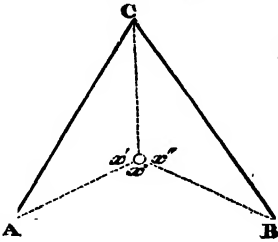


Fig. I.

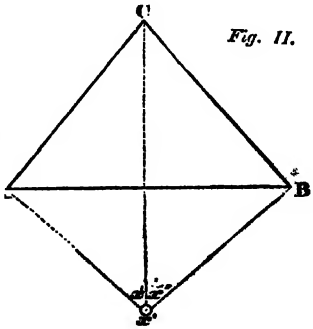
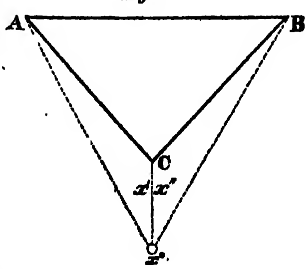


Fig. II.

The position of each Village may be thus determined, by ascertaining the values of the angles subtended from it to three points of the surrounding secondary triangles, the azimuth of the lines connecting the latter give the azimuth of any of the lines of the subtended angles from the points in question.

In the annexed diagrams A, B and C are the three given Stations. Forming A, B and C into a triangle, designate the angles thereof by the letters which mark the Stations; the sides opposite thereto being represented by the corresponding small letters of the alphabet a, b, c. It is evident that the angles A, B and C, as well as the sides a, b and c, are known elements.

Fig. III.



Supposing x to be the Station whose position is required to be determined, designate as follows the angles observed thereat:

$$x^\circ = \angle \text{ between } A \text{ and } B$$
$$x' = \angle \text{ between } A \text{ and } C$$
$$x'' = \angle \text{ between } B \text{ and } C$$

Now Station x may be either *within* the given triangle or *without* it. In the former case, $x^\circ + x' + x'' = 2\pi$; and in the latter $x' + x'' = x^\circ$. The first of these cases is represented by figure 1, and the latter by figures 2 and 3.

With regard to figures 2 and 3, it will be seen, that the difference between them consists in the line AB being placed in the former case between Stations C and x, and in the latter on one side thereof. This circumstance should be borne in mind, as the general formula, whereby diagrams 1 and 2 are solved, will require a slight modification when applied to diagram 3.

When a particular case of the problem under consideration is offered for solution, the Surveyor will draw a sketch thereof and compare it with diagrams 1 and 2 and 3. The sketch must agree with one of the diagrams. Holding the sketch in the same way as the diagram corresponding thereto is drawn in the book, the Surveyor will designate the several distances and angles in the sketch by those symbols, which are employed to denote similar elements in the diagram in question. This being done and calling A' the angle at Station A between C and x, it will be found that—

$$\text{Cot } A' = \frac{b \sin. x''}{a. \sin. x' \sin. (C + x' + x'')} - \cot (C + x' + x'')$$

In computing by this formula it will be remembered that Δ C must be used as it stands for diagrams 1 and 2. But for diagram 3, its complement to 360° will require to be employed in place of the original $\angle$ C.

After due regard to the preceding rule, compute the two terms composing the value of cotangent A' and take out the result in natural numbers

carried to 7 decimals. The signs of the natural numbers will be known on reference to the following table, the argument whereof is the numerical value of $(C + x' + x'')$.

Table exhibiting the signs of $\dfrac{b \text{ sin. } x''}{a \text{ sin. } x' \text{ sin. } (C + x' + x'')}$ and cot. $(C + x' + x'')$.

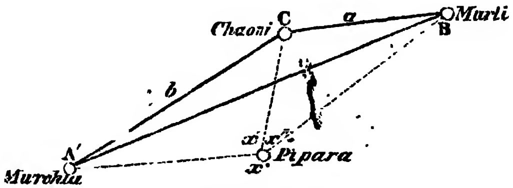
Values of $(C + x' + x'')$	Signs of $\dfrac{b \text{ sin. } x''}{a \text{ sin. } x' \text{ sin. } (C + x' + x'')}$	Signs of cot. $(C + x' + x'')$
1st Quadrant ...	—	—
2nd Quadrant ...	—	+
3rd Quadrant ...	+	—
4th Quadrant ...	+	+

After affixing proper signs to the natural numbers, add them together, the sum is the natural cotangent of A': or when a table of natural cotangents is not at hand, the logarithm of the sum may be taken, which is the logarithmic cotangent of A', the logarithm being taken without reference to the sign of the sum, which may be either positive or negative.

When the sum is positive, the tabular arc corresponding to the computed cotangent is the value of A'; when it is negative, the supplement to the tabular arc is the required value of A'. $\angle A'$ being determined, the other angles of the triangles formed by the point sought and the three known Stations may be easily deduced by the simple operations of addition and subtraction.

Example.

Murchia, Chaoni, and Murli, being observed from Pipara, it is required to compute the position of the last-mentioned point.



Elements given.

Side Chaoni to Murli	a	Log.	4·4766465
Side Chaoni to Murchia	b	Log.	4·7187414
$\angle$ Chaoni, between Murli and Murchia...	C..	..	158° 38′ 38″

Observed Angles at Pipara.

		°	′	″
Between Murli and Murchia	$x^{\circ} =$	150	18	24
Between Murchia and Chaoni	$x' =$	107	29	10
Between Chaoni and Murli	$x' =$	42	49	14

Elements sought.

∠Murchia between Pipara and Chaoni or A′

Type of Calculation.

					1st Term.		*2nd Term.*
$C =$	158°	38′	38″				
$x' =$	107	29	10	Cosec.	0·0205473		
$x'' =$	42	49	14	Sin.	9·8323201		
$C + x' + x'' =$	308	57	2	Cosec.	0·1091942		
b	...	...	...	Log.	4·7187414		
a	...	...	A. C. of	Log.	5·5233535		
					0·2041565	Cot.	9·9076028
				+	1·6001344	+	0·8083564
				+	0·8083564		
	Cot.	A′ =		+	2·4084908	Log.	0·3817450
							A′ = 22° 32′ 54″

In carrying on a Detail Survey, it sometimes happens that the Theodolite cannot be planted over the centre of a Station. When this is the case, the instrument may be placed on one side of it, and angles taken to the surrounding signals. It is clear that these angles, before they can be employed in the computation of the triangulation, will require to be transferred to the centre of Station, the geometrical construction for which problem was given at page 21. This reduction may be easily effected in the following manner:

Reduction of angles to the centre of a Station.

Of the two points (A and B) observed from a Station C, that may be called the right hand point, the reading of which, in the deduction of an angle, is used as the subtrahend; the other point, whose reading is employed as the subtractor in the same operation, being styled the left hand point.

Considering the reading of the true centre as 0° 0′ 0″, observe or compute, as may be necessary, from the centre of observation, the readings of Stations A and B. Call these readings A' and B'.

Likewise let α and β represent the distances of Station C to Stations A and B respectively: which distances are obtained from an approximate computation of ΔABC by using the angles as they are derived from observation unaltered by any correction.

And lastly, let ϵ designate the distance derived from measurement of true centre from centre of observation.

Now compute the two following terms, and prefix thereto the signs given in the table subjoined.

$$\delta A = \frac{\varepsilon \sin A' \operatorname{cosec} 1''}{\alpha} \qquad B = \frac{\varepsilon \sin B' \operatorname{cosec} 1''}{\beta}$$

The numerical values of these terms will be in seconds, the sum whereof is the correction required to the observed angle between A and B.

Table exhibiting the signs of the foregoing corrections.

Reading of Station A by considering the reading of the true centre as 0° 0′ 0″.	Signs of Corrections for Station A.	
	When Station A is left hand point.	When Station A is right hand point.
1st Quadrant	−	+
2nd Quadrant	−	+
3rd Quadrant	+	−
4th Quadrant	+	−

EXAMPLE.

At the secondary Station of Manda of the Gurwani Meridonial Series, the Theodolite in one instance was not placed over the Station centre, but at the distance of 11·67 feet from it, on which occasion the angle taken was that between the Station C' and Baraganj Temple, the correction to which for eccentricity may be deduced as follows :—

To compute the correction for Station C', left hand point.

From centre of observation, Reading of Station C' by considering 0° 0′ 0″ as the reading of true centre	128° 4′ 20″	Sin.	9·89610
Distance from centre of observation to true centre ...	11·67 feet	Log.	1·06707
Approximate distance from Manda to Station C' in feet	A. C. of	Log.	5·42404
Cosec. 1″	Constant	Log.	5·31443
1st part of correction...	— 50″·3	Log.	1·70164

To compute the correction for Baraganj Temple, right hand point.

From centre of observation reading of Baraganj Temple by assuming true centre to read 0° 0′ 0″,	195° 14′ 40″	Sin.	9.41985
Distance from centre of observation to true centre ...	11·67 feet	Log.	1·06707
Approximate distance from Manda to Baraganj Temple in feet	A. C. of	Log.	6·05584
Cosec. 1″	Constant	Log.	5·31443
2nd part of correction ...	— 72″·0	Log.	1·85719

ence the total correction is—50·3—72·0	=	— 0° 2′ 2′	
Observed Angle,	=	67 10 20	
Corrected Angle,	=	67 8 18	

CHAPTER IX.

Barometrical Heights.*

To determine barometrically the difference of height between two places, the implements required are two Barometers with their attached Thermometers and two detached common air Thermometers.

It is of course preferable to have two Barometers and to make simultaneous observations, as during changeable weather dependance cannot be placed upon results with one only; particularly if *any considerable interval of time* has elapsed between the comparison of the heights of the mercury at the different stations. Even the method of noting the time of each observation, ending the day's work at the spot where it was commenced, and then correcting the readings of the Barometer and Thermometer at each Station, for the proportion of the total change between the first and last reading due to the respective intervals of time, cannot of course render observations taken with one Barometer equal in accuracy to those observed simultaneously with two instruments, unless the rise or fall of the Barometer, and particularly of the Thermometer, was ascertained to have been *uniformly progressive* during the whole day. Observing, however, the Barometer again at the first station at close of the day has this advantage, that any great change during the period will be immediately detected, and the degree of dependance to be placed on the observation made evident.

The difference of readings owing to these changes will also be generally subdivided among a number of observations, though instances *may* occur where this caution, *as regards the Thermometer,* will be productive of error in the result.

In exploratory expeditions into distant countries, where it is obviously impracticable to make simultaneous observations at the different elevations as they are met with in the course of each day's journey, the comparisons must be instituted with the observations taken at any fixed observatory, and which are generally published for general information, or at any known Station, the height of which has been *previously determined.* To effect this, the traveller's instrument must, of course,

* See also Part II. Chapter, 7.

in the first instance, be duly compared with the standard in the observatory, the height of which above the sea level is known; or with the instrument left at any particular Station, where the hours for observation have been previously mutually agreed on.

The two Barometers selected for the measurement of heights, having been compared with each other, the difference, if any, existing between them will be determined. The whole of this difference called the *Index Error* being applied as a correction to one or the other Barometer, their readings will obviously become equalized.

Under ordinary circumstances, probably ten comparisons at intervals of a few minutes from each other, after at least half an hour's quiet exposure of both instruments side by side, would be sufficient for the correct determination of the Index error abovementioned; but in cases where the Barometers do not maintain a constant difference, twenty, thirty, or even forty comparisons may be taken with advantage. Previous to every trial, the Barometers ought to be thrown out of adjustment and then readjusted and observed. After every fourth or fifth comparison the Barometers should be reversed and put up again.

While the Barometer comparisons are going on, the attached and detached Thermometers may likewise be compared The mean difference between the two attached, as likewise that between the two detached, Thermometers being computed, they should be used in the same way as the mean difference between the two Barometers, *viz.*, for equalizing their readings.

After these preliminary comparisons have been executed, the measurement of a height by barometrical observation may be taken in hand. For this purpose an observer with a Barometer and a detached Thermometer being placed at the lower Station, and another observer with similar instruments being posted at the upper, let them observe simultaneously, that is to say, at certain times previously fixed upon, continuing the observations for as many days as may be convenient. If the weather during the observations be clear and steady, then the difference of height derived from this measurement would be worthy of great confidence.

For the deduction of a height from barometrical observations the formula commonly made use of, is that given by La Place. It takes into account the indications of the Barometer and Thermometer, but not those of the Hygrometer. Perhaps this omission is a defect of La Place's process of computation. Professor Bessel has investigated a formula in which the three conditions abovementioned have been made use of. We are not aware that this formula has been tested by a sufficient number of experiments to warrant its introduction into this work.

In computing by La Place's formula, the symbols used for designating observed elements are as follows :—

Observed Elements.		Stations.	
		Upper.	Lower.
Height of Thermometer in open air	...	t'	t
" Thermometer attached	...	T'	T
" Barometer	...	β'	β

This being premised, it will not be difficult to explain the process of computation. The barometrical columns β and β' represent atmospheric pressure at the two given Stations, and as the lengths of these columns vary with the temperature (T' and T) of the mercury, it is clear that before they can be used as elements of computation, they will require reduction to one common temperature. Again, the atmosphere itself as regards density does not remain in one invariable mean state; it is undergoing continual changes, produced by the greater or smaller amount of heat existing therein, and indicated by t and t'. This being the case, it is clear that the correction for temperature must form an important part of the deduction of the difference of height from the difference of atmospheric pressure at two given places. And lastly, the force of gravity should likewise be taken into account, which, under a given latitude, varying with the height ascended, must, though in a small degree, influence and modify atmospheric pressure at different elevations.

These are the general considerations upon which La Place's formula for the deduction of height is based, and in order that the corrections which they give rise to may be of easy computation, Tables A, B, C are subjoined. It will be seen that A furnishes the correction for the temperature of the atmosphere, B, for that of the mercury, and C, for that of gravity under any latitude λ.

We will explain the use of one of these Tables, A for instance, as that explanation will serve for the others. Enter this Table with the numerical value of $(t+t')$. If that value be forthcoming in the Table, then the quantity opposite is the proper value of A.

Table for determining Altitudes with the Mountain Barometer.

THERMOMETERS IN OPEN AIR.

$t+t'$	A.	$t+t'$	A.	$t+t'$	A.	$t+t'$	A.
°		°		°		°	
40	4·76891	80	4·78830	120	4·80686	160	4·82466
41	4·76940	81	4·78877	121	4·80731	161	4·82509
42	4·76990	82	4·78924	122	4·80777	162	4·82553
43	4·77039	83	4·78972	123	4·80822	163	4·82596
44	4·77089	84	4·79019	124	4·80867	164	4·82640
45	4·77138	85	4·79066	125	4·80912	165	4·82683
46	4·77187	86	4·79113	126	4·80957	166	4·82727
47	4·77236	87	4·79160	127	4·81003	167	4·82770
48	4·77286	88	4·79207	128	4·81048	168	4·82813
49	4·77335	89	4·79254	129	4·81093	169	4·82856
50	4·77384	90	4·79301	130	4·81138	170	4·82900
51	4·77433	91	4·79348	131	4·81183	171	4·82943
52	4·77482	92	4·79395	132	4·81227	172	4·82986
53	4·77530	93	4·79442	133	4·81272	173	4·83029
54	4·77579	94	4·79488	134	4·81317	174	4·83072
55	4·77628	95	4·79535	135	4·81362	175	4·83115
56	4·77677	96	4·79582	136	4·81407	176	4·83158
57	4·77725	97	4·79628	137	4·81451	177	4·83201
58	4·77774	98	4·79675	138	4·81496	178	4·83244
59	4·77823	99	4·79721	139	4·81540	179	4·83286
60	4·77871	100	4·79768	140	4·81585	180	4·83329
61	4·77920	101	4·79814	141	4·81629	181	4·83372
62	4·77968	102	4·79860	142	4·81674	182	4·83415
63	4·78016	103	4·79907	143	4·81718	183	4·83457
64	4·78065	104	4·79953	144	4·81763	184	4·83500
65	4·78113	105	4·79999	145	4·81807	185	4·83542
66	4·78161	106	4·80045	146	4·81851	186	4·83585
67	4·78209	107	4·80091	147	4·81895	187	4·83627
68	4·78257	108	4·80137	148	4·81939	188	4·83670
69	4·78305	109	4·80183	149	4·81984	189	4·83712
70	4·78353	110	4·80229	150	4·82028	190	4·83754
71	4·78401	111	4·80275	151	4·82072	191	4·83797
72	4·78449	112	4·80321	152	4·82116	192	4·83839
73	4·78497	113	4·80367	153	4·82160	193	4·83881
74	4·78544	114	4·80412	154	4·82203	194	4·83923
75	4·78592	115	4·80458	155	4·82247	195	4·83966
76	4·78640	116	4·80504	156	4·82291	196	4·84008
77	4·78687	117	4·80549	157	4·82335	197	4·84050
78	4·78735	118	4·80595	158	4·82378	198	4·84092
79	4·78782	119	4·80640	159	4·82422	199	4·84134
80	4·78830	120	4·80686	160	4·82466	200	4·84176

Attached Thermometers.				Latitude of the place.			
$T-T'$	$B.$	$T-T'$	$B.$	λ	$C.$	λ	$C.$
0°	0·00000	20°	0·00087	8°	0·00112	24°	0·00078
1	0·00004	21	0.00091	9	0·00111	25	0·00075
2	0·00009	22	0·00096	10	0·00110	26	0·00072
3	0·00013	23	0·00100	11	0·00108	27	0·00690
4	0·00017	24	0·00104	12	0·00107	28	0·00065
5	0·00022	25	0·00109	13	0·00105	29	0·00062
6	0·00026	26	0·00113	14	0·00103	30	0·00059
7	0·00030	27	0·00117	15	0·00100	31	0·00055
8	0·00035	28	0·00122	16	0·00099	32	0·00051
9	0·00039	29	0·00126	17	0·00097	33	0·00048
10	0·00043	30	0·00130	18	0·00095	34	0·00044
11	0·00048	31	0·00134	19	0·00092	35	0·00040
12	0·00052	32	0·00139	20	0·00090	36	0·00036
13	0·00056	33	0·00143	21	0·00087	37	0·00032
14	0·00061	34	0·00147	22	0·00084	38	0·00028
15	0·00065	35	0·00152	23	0·00081	39	0·00024
16	0·00069	36	0·00156	24	0·00078	40	0·00020
17	0·00074	37	0·00160				
18	0·00078	38	0·00165				
19	0·00083	39	0·00169				
20	0·00087	40	0·00173				

If it be not forthcoming, then take out A for $(t+t')$ next less, and correct it in this way:—Compute the difference between the Tabular quantities next less and next greater than the required value. Multiply this difference by the excess of the given argument above the Tabular argument next less; the product is the correction required, which is positive, because the Tabular quantity A forms an increasing series. In a similar manner, quantities B and C may be computed.

Calculating B, A, D, and C from the Tables given above, and taking out the Logarithms of β and β' from a common Table of Logarithms, the computation of the difference of height may be effected in the following manner:—

$$\text{Put } D = \text{Log. } \beta - (\text{Log. } \beta + B)$$

$$\text{Hence Log. } x = \text{Log. } D + A + C.$$

x being the difference of altitude in feet between the two Stations.

Deduction of the Height of Sonakoda G. T. Station above Calcutta Observatory, by using the six simultaneous Barometrical Observations made at both places on the 6th December, 1847.

Mean Latitude, = 24° 24′	(Table column C.) 0·00077
Upper Station, Sonakoda,	Lower Station, Calcutta Observatory.

Upper.		Lower.
Thermometer in open air,...	$t' = 70°\cdot8$	$t = 72°\cdot8$
Thermometer attached......	$T' = 70°\cdot8$	$T = 73°\cdot2$
Barometer...	$\beta' = 29''\cdot957$	$\beta = 30''\cdot169$

$(T - T') = 2\cdot4$ (Table, column B.) 0·00011; $(t + t') = 143\cdot6$ (Table, column A.) 4·81745

$\therefore B = 0\cdot00011$		.................................Log. = 3.46982
Log. $\beta' = 1\cdot47650$		from Column C = 0·00077
		from Column A = 4·81745
Log. $\beta' + B$ 1.47661		
Log. β... = ·147956		2·28804
Difference = 0·00295	Log...	Difference of height = 194·1 feet.

The Barometers used at Sonakoda were those marked Nos. 2 and 3 by Troughton and Simms, of which the mean is taken as the numerical value for β'. The standard Barometer, No. 86, by Newman, was observed at the Calcutta Observatory.

	Feet.
By six corresponding barometrical observations on the 6th December, 1847, the mean height of the cisterns of Barometers, Nos. 2 and 3, above the cistern of the Calcutta Barometer as deduced above is	194·1
By six similar observations on the 7th December	192·1
Ditto ditto 8th ditto	194·7
Mean	193·6
The cisterns of Nos. 2 and 3 above the station mark ...	− 2·0
Ditto of Calcutta Barometer above sea level	+ 18·2
Height of Sonakoda Station above sea level barometrically ...	209·8
The same deduced geodetically	213·8
Discrepancy ...	4·0

The deduction of this height of the Sonakoda Base in the Purneah district at a distance of 255 miles from Calcutta, agrees, as will be perceived, remarkably well with the Trigonometrical Calculation, the difference being only 4 feet. This proves the advantage of the systematic

record of meteorological observations at a fixed observatory. The scientific researches of an officer lately employed in Kumaon tend to prove that his barometrical observations even across the Himalaya, follow all the Calcutta movements; and this view of the subject is confirmed by the deductions of the heights of the several mountains in Sikhim and Eastern Nepal by the accomplished traveller, lately traversing those parts, by means of similar simultaneous data, which have approximated in a remarkable manner* to the trigonometrical results obtained by the Surveyor General of India. This adds, therefore, a peculiar value to the Calcutta Register, and renders the observations there taken of great service to the traveller. The *day* curves given in this register are quite perfect, but it wants the 3 *a.m.* and 10 *p.m.* observations to make it complete as a meteorological record.

An example of the difference of elevation between the top of the monastery hill at Darjeeling and Mr. Muller's house at the same place, worked out by Bessel's and La Place's formulæ, gives the following results:

				Feet.
By Bessel	...	...	...	214·20
By La Place	...	...	...	214·35
Difference		...	...	0·15

and agreeing with the trigonometrical height by 0.9 feet. The difference, therefore, caused by the hygrometric state of the atmosphere, and allowed for by Bessel, but not taken into account by La Place, does not appear to be worthy of notice.

A set of most useful "Tables for determining the altitudes of mountains by the Barometer and boiling point Thermometer" have been published by Colonel J. T. Boileau, the late Superintendent of the Simlah Magnetic Observatory,* and no traveller should go without them. The *barometrical* Tables, computed from Oltmann's formulæ, are particularly convenient, especially for persons who are not accustomed to logarithms. "The comparisons of English and French measures and of the different Thermometers" are also frequently required for reference in a country where you cannot always choose your own instruments, or foresee whether a Centigrade, Reaumur, or Fahrenheit Thermometer is to be used. The *thermometrical* Tables for finding the heights of the Barometer corresponding to different boiling points, have been computed from Regnault's Table of the Elastic Forces of aqueous vapour, published in Taylor's Scientific Memoirs, volume 4th, to every tenth of a degree of

* Printed at the Magnetic Observatory Press, Meerut, July, 1849.

Fahrenheit. The whole of these Tables are too elaborate for anything beyond a passing remark in this work, but we may safely recommend the compilation to general notice, and express a hope that the intention hinted at in the Preface "of a reprint with additions," may be speedily carried out. We must therefore content ourselves with giving a general explanation of this latter mode of proceeding for the determination of heights.

THERMOMETRICALLY.*

Those only who have had any practical experience with such delicate and expensive instruments as Mercurial Mountain Barometers, can be fully aware of the disappointments met with in a country like this, where the dangers and difficulties experienced with instruments of this description are so constant, and the means of transit so unsuited to their use and for replacing them from such great distances; any substitute, therefore, by which the heights of places may be measured, cannot fail to be extremely useful in many instances and situations, which are perpetually occurring with travellers and explorers in the countries

* *On the use of common Thermometers to determine Heights.*

Having been recently applied to by two gentlemen about to travel—the one in Africa and the other in Asia Minor—for a description of the Thermometers and apparatus used by myself for some years in India for determining heights by the boiling temperature of water, I have ventured to believe that a brief account of a process which I found to produce results sufficiently near to the truth for most practical purposes, may not be unacceptable to some members of the Society, particularly as I carried on my barometrical observations contemporaneously, and thereby obtained data for fixing the value of certain points on the thermometric scale. To determine heights accurately, good Barometers are necessary, which have been carefully compared with a standard Barometer: the observations must be taken simultaneously at the upper and lower stations, and the temperature of the mercury and the air, and the hygrometric state of the latter, must be noted. Heights so determined, when tested again in the same or succeeding years, I have rarely found to vary more than 10 or 20 feet in 4000 or 5000. When Barometers are used which have not been previously compared with a standard, when the observations are not simultaneous, and when the pressure and temperature at the level of the sea are *assumed*, the results may, by accident, be near to the truth, but they will usually be from 100 to 300 feet wrong—at least such is the result of my experience within the Tropics. But good Barometers are very costly; they are troublesome to carry, are particularly exposed to accident on a journey, and get out of order by the escape of the mercury, which, being frequently unobserved, the Barometer continues to be used as if it were correct. The late Archdeacon Wollaston, aware of these facts, invented the thermometric Barometer to supply the place of the ordinary Barometer. This instrument is very sensible, but it is very fragile from the great weight of the bulb compared with the slenderness of the stem; moreover, there are some complex accompaniments, and the instrument is also expensive: in short, I found it not fit for *rough work* out of doors, having had three destroyed at the outset of my labours; and the same opinion is expressed by Mr. James Prinsep, of Calcutta, who is well known for the practical application of his scientific knowledge. I had then recourse to common Thermometers, and, with certain precautions in their use, found them answer my purpose sufficiently well. A tin shaving-pot was my boiler; dry sticks and pure water were usually to be had, and by the time my Barometers

bordering on the British possessions in India. The *common Thermometer* has been frequently practised in India for determining heights

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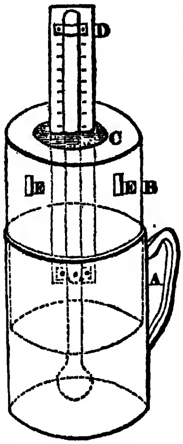
were settled, I was ready to take the boiling temperature. The following is a sketch of the apparatus:—



A. A common tin pot, 9 inches high by 2 in diameter.
B. A sliding tube moving up and down in the pot; the head of the tube is closed, but has a slit in it C, to admit of the Thermometer passing through a collar of cork which shuts up the slit where the Thermometer is placed.
D. Thermometer, with so much of the scale left only as may be desirable.
E. Holes for the escape of steam.

It will be seen that the chief part of the scale usually attached to the Thermometer is removed, only so much of it being left as may be desirable: I, however, permitted the brass scale of one of my Thermometers to remain, and I did not discover that it was the cause of error. Previously to taking the Thermometers inland, it is necessary to ascertain their boiling points at the level of the sea; for in many instances the scales are so carelessly applied, that a Thermometer may indicate a boiling temperature of 213°, 214°, or 215° at the level of the sea; one of mine stood of 214°·2 when water boiled. Nevertheless, by making a deduction of 2°·2 in all observations, the indications rarely differed five-hundredths of a degree from the other Thermometer, of which the boiling point was 212°: the temperature of the air and the height of the Barometer at the time the *verification* of the Thermometers is made, must be noted. The following is the manner in which my observations were taken:—from 4 to 5 inches of *pure* water were put into the tin pot; the Thermometer was fitted into the aperture in the lid of the sliding tube by means of a collar of cork; the tin tube was then pushed up or down to admit of the bulb of the Thermometer, being about *two inches* above the bottom of the pot. Violent ebullition was continued for ten minutes or a quarter of an hour, and the height of the mercury was repeatedly ascertained during that time, and the temperature of the air was noticed. Similar operations were repeated with a *second* Thermometer, for it is never safe to rely upon *one* instrument. Having obtained the boiling points, it remains to determine the value of the indication of diminished pressure when the observations are taken above the level of the sea. The elastic tension of steam at different points on the thermometric scale has been determined by experiment, but not at regular intervals on the scale, nor with similar results, by different persons: Tables, therefore, computed from the formulæ of the various experimenters, do not accord; but in three Tables which I have in my possession, the heights computed by them, when compared with heights determined by corresponding barometrical observations with previously compared Barometers (the only satisfactory way to ascertain heights not taken trigonometrically), approximate sufficiently near for all practical purposes where great accuracy is not desired. These Tables, however, differ slightly from each other.

The Table which first came into my hands appeared anonymously in the *Madras Gazette*, for 1824. In 1826, an able friend, Lieut. Robinson, of the Indian Navy, who entered warmly into my views to determine heights by common Thermometers, thought he could improve upon the table I was using, and accordingly made a new computation; the third Table came under my notice much more recently than the two former. It is computed by Mr. James Prinsep, of Calcutta, Secretary of the Asiatic Society of Bengal, a gentleman distinguished for his scientific research. He published it in the Journal of the Society. To admit of a just estimate being formed of the value of these Tables,—of the value of corre-

by the different temperatures of *boiling water*. According as the atmospheric pressure diminishes, so does water boil at lower temperatures, and

sponding barometrical observations, made with due precautions, although with different coadjutors and different instruments,—of the value of barometrical observations, with an assumed pressure and temperature, at the level of the sea,—of the value of thermometrical compared with barometrical observations,—out of many hundred heights determined in various ways, I have taken many at random (the number, it appears, is eighty-eight) and I have put them into juxtaposition in a Tabular form. In thermometric heights the elements at the level of the sea were a boiling temperature of 212° Fahr. and a mean temperature of the air of 82°. The *assumed* pressure in heights determined barometrically without corresponding observations, was 30 inches; mean temperature 82°. In looking over the tabulated results, I was a good deal surprised to find that in no instance, by whatever method determined, do the barometric differences in height exceed 127 feet, and this only by comparing the highest indications with an assumed pressure with the lowest indications of corresponding observations. It will be seen that the various Tables for determining heights thermometrically, with certain exceptions, do not differ very *materially* in their results from each other, nor from corresponding barometric observations; the formulæ on which they are founded may therefore be considered, on the whole, sufficiently accurate for the present state of our knowledge.

Lieut. Robinson's and Mr. Prinsep's Tables give close approximations to each other in their results, but they are so much below the corresponding barometric observations, which I consider the true heights, as the results by the Madras Table are above the true heights. Some of them curiously coincide within a foot or two of the heights determined by corresponding barometrical observations, but this coincidence must be the result of mere accident. Taking the mean of all the thermometric observations at a station calculated by the three Tables, and the mean of all the corresponding barometric observations at the same place, the utmost difference is 107 feet in less than 600; and the least difference is 8 feet in about 3000; but as the thermometric heights, in which the difference of 107 feet occurs, were single observations, made by a gentleman who had newly begun to use his Thermometers, they may be looked upon as probably less accurate than subsequent trials would have made them. This is scarcely an unjust inference, as it will be seen that the next greatest difference made by the same gentleman was only 24 feet in 4490. It must be admitted, however, that this amount of error is just as likely to occur in heights of 100 feet as in those of 10,000. My Thermometers were not graduated to less than half-degrees, and long practice enabled me to determine the height of the mercury in the steam to one-twentieth of a degree; but I would recommend Thermometers being used in which the degrees are graduated to fifths or tenths of a degree. On the whole, I think the results of six years' experience justify me in saying that common Thermometers may be satisfactorily used to supply the place of Barometers in measuring heights where great accuracy is not required; and it will be recollected that what is usually looked upon as a difficult and troublesome operation with Barometers, will be attainable by any person who carries with him a couple of Thermometers, the requisite tin pot, and the Tables, and who is master of the simplest rules of arithmetic.

Of the three Tables in my possession, I have chosen Mr. Prinsep's, from their perspicuity and the facilities they offer for the conversion of boiling temperatures into heights with very little trouble; but a glance over the figures in my Tables of Altitudes will show that the Tables are susceptible of considerable improvement, for, with two exceptions, all the heights deduced from Mr. Prinsep and Lieut. Robinson are much below those determined by simultaneous observations with good Barometers; and I join with Mr. Prinsep in expressing a hope that every traveller boiling his Thermometers will, at the same time, if he possess a Barometer, make a record of its indication, and thus render essential service to physics, by fixing so many points on the scale of the elastic tension of steam at different temperatures.

[PART IV.

thus the boiling point of water at different heights is computed to measure these heights. The Thermometer used for this particular purpose, is described by Lieut.-Colonel W. H. Sykes, F.R.S., in the 8th volume of the London Geographical Journal, wherein he has also given the Tables deduced by the late James Prinsep, to facilitate the computation of altitudes, as well as examples for their practical application. These we have given in the foot notes, rendering but little further explanation necessary. The instrument with boiling apparatus complete is extremely simple, and any Thermometer with metal scale, reading sufficiently high, may be adapted to the *shaving pot* as described by Colonel Sykes. The great portability, and less liability to injury over the Barometer is the chief recommendation of this instrument, for of course the same accuracy cannot be expected from it. The results deduced from the use of these Tables appear always *rather less* than those obtained from careful barometrical observations, and if a number of careful observations obtained by both methods are compared together, or with a trigonometrical or levelling process, they will afford the means of making any necessary corrections in the Tables. The approximation, however, is sufficiently close in the examples given in Colonel Sykes' book, as to induce great confidence in the method, and especially for determining the *comparative* altitudes of places in a mountainous country.

TABLE I.

To find the Barometric Pressure and Elevation corresponding to any Observed Temperature of Boiling Water between 214° and 180°.

Boiling Point of Water.	Barometer modified from Tredgold's Formula.	Logarithmic Differences or Fathoms.	Total Altitude from 30 00 in. or the Level of the Sea.	Value of each Degree in Feet of Altitude.	Proportional Part for One-tenth of a Degree.
°	Inches.		Feet.	Feet.	Feet.
214	31·19	00·84·3	—1013	—505	...
213	30·59	84·5	507	—507	...
212	30·00	84·9	0	+509	...
211	29·42	85·2	+ 509	511	51
210	28·85	85·5	1021	513	...
209	28·29	85·8	1534	515	...
208	27·73	86·2	2049	517	...
207	27·18	86·[illegible]	2566	519	52
206	26·64	87·1	3085	522	...
205	26·11	87·5	3607	524	...
204	25·59	87·8	4131	526	...
203	25·08	88·1	4657	528	...
202	24·58	88·5	5185	531	53
201	24·08	88·9	5716	533	...
200	23·59	89·3	6250	536	...
199	23·11	89·7	6786	538	...
198	22·64	90·1	7324	541	54

The Fourth column gives the Heights in Feet.

TABLE I.—*(Continued.)*

Boiling Point of Water.	Barometer modified from Tredgold's Formula.	Logarithmic Differences or Fathoms.	Total Altitude from 30·00 in. or the Level of the Sea.	Value of each Degree in Feet of Altitude.	Proportional Part for One-tenth of a Degree.
	Inches.		Feet.	Feet.	Feet.
197	22·17	90·5	7864	543	...
196	21·71	91·0	8407	546	...
195	21·26	91·4	8953	548	...
194	20·82	91·8	9502	551	55
193	20·39	92·2	10053	553	...
192	19·96	92·6	10606	556	...
191	19·54	93·0	11161	558	...
190	19·13	93·4	11719	560	56
189	18·72	93·8	12280	563	...
188	18·32	94·2	12843	565	...
187	17·93	94·8	13408	569	57
186	17·54	95·3	13977	572	...
185	17·16	95·9	14548	575	58
184	16·79	96·4	15124	578	...
183	16·42	96·9	15702	581	...
182	16·06	97·4	16284	584	...
181	15·70	97·9	16868	587	...
180	15·35		17455		59

The Fourth column gives the Heights in Feet.

The Tables being given in degrees of *Fahrenheit,* it will be necessary in case *Centigrade* Thermometers are used, to convert these indications into the corresponding ones of Fahrenheit, for which the formula is $F = \frac{9c}{5} + 32$ whenever the degrees are above the freezing point of water, and *vice versâ;* for converting Fahrenheit into Centigrade measure, the formula will be $C = \frac{(F - 32) \times 5}{9}$

TABLE II.

Table of Multipliers to correct the Approximate Height for the Temperature of the Air.

Temperature of the Air.	Multiplier.	Temperature of the Air.	Multiplier.	Temperature of the Air.	Multiplier.
° 32	1·000	° 43	1·023	° 54	1·046
33	1·002	44	1·025	55	1·048
34	1·004	45	1·027	56	1·050
35	1·006	46	1·029	57	1·052
36	1·008	47	1·031	58	1·054
37	1·010	48	1·033	59	1·056
38	1·012	49	1·035	60	1·058
39	1·015	50	1·037	61	1·060
40	1·017	51	1·039	62	1·062
41	1·019	52	1·042	63	1·064
42	1·021	53	1·044	64	1·066

TABLE II.—*(Continued.)*

Temperature of the Air.	Multiplier.	Temperature of the Air.	Multiplier.	Temperature of the Air.	Multiplier.
° 65	1·069	° 74	1·087	° 83	1·106
66	1·071	75	1·089	84	1·108
67	1·073	76	1·091	85	1·110
68	1·075	77	1·094	86	1·112
69	1·077	78	1·096	87	1·114
70	1·079	79	1·098	88	1·116
71	1·081	80	1·100	89	1·118
72	1·083	81	1·102	90	1·121
73	1·085	82	1·104	91	1·123

Enter with the mean temperature of the stratum of air traversed, and multiply the approximate height by the number opposite for the true altitude.

When the Therometer has been boiled at the foot and at the summit of a mountain, nothing more is necessary than to deduct the number in the column of feet opposite the boiling point below from the same of the boiling point above; this gives an approximate height, to be multiplied by the number opposite the *mean* temperature of the air in Table II. for the correct altitude.

	°	feet.
Boiling point at summit of Hill Fort of Púrundhur, near Púna	204·2 =	4027
Boiling point at Hay Cottage, Púna	208·7 =	1690
Approximate height		2337
Temperature of the air above	75°	
Ditto ditto below	83	
Mean 79 = Multiplier		1·098
Correct altitude		2·566 feet.
Mean of Barometer Observations		2·649
Difference		— 83

When the boiling point at the upper station alone is observed, and for the lower the level of the sea, or the register of a distant Barometer is taken, then the barometric reading had better be converted into feet, by the usual method of subtracting its logarithm from 1·47712 (log. of 30 inches) and multiplying by ·0006, as the differences in the column of "*Barometer*" vary more rapidly than those in the "*feet*" column.

Example.—Boiling point at upper station ... ... 185° = 14548

Barometer at Calcutta (@ 32°) 29 in. 75°

Logar. diff. = 1·47712 — 1·47349 = 00363 × 0006 ... = 218

Approximate height 14330

Temperature, upper station, 76° } 80 = multiplier 1·100
Ditto lower 84° }

Correct altitude 15763

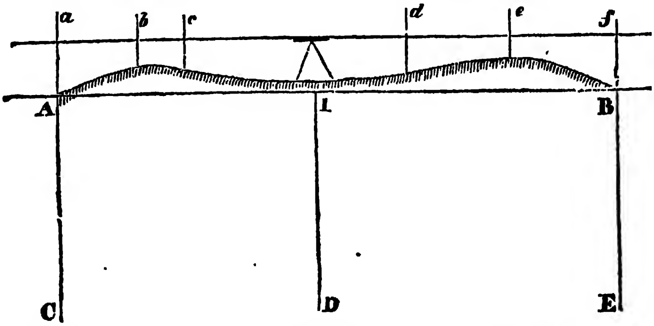
Assuming 30·00 inches as the average height of the Barometer at the level of the sea (which is, however, too much), the altitude of the upper station is at once obtained by inspection of Table I., correcting for temperature of the stratum of air traversed by Table II.

CHAPTER IX.]

CHAPTER X.

LEVELLING.

LEVELLING is the art of tracing a line at the surface of the earth, which shall cut the directions of gravity everywhere at right angles. If the earth were an extended plane, all lines representing the direction of gravity at every point on its surface would be parallel to each other; but in consequence of its figure being that of a sphere or globe, they every where converge to a point within the sphere which is equidistant from all parts of its surface; or, in other words, the direction of gravity invariably tends towards the centre of the earth, and may be considered, as represented by a plumbline when hanging freely, and suspended beyond the sphere of attraction of the surrounding objects.



In the above diagram let the *straight* line *AB* represent the surface of the earth, upon the supposition of its being an extended plane, the direction of gravity at the points *A*, *I*, and *B* would be represented by the lines *AC*, *ID*, and *BE*, all parallel to each other, and at right angles to the horizontal line *AB*. Now if the surface was undulatory, as shown by the *curved* line *AB*, and it was required to make a section representing it, an instrument, capable of tracing out a line parallel to the horizontal line *AB* (as a spirit-level) might be set up anywhere on the surface, as at *I*, and staves being placed or held along the line, as at *a*, *b*. *c*, *d*, *&c.*, the different heights above the ground where such staves were intersected by the lines so traced out, would at once show the relative level of all those points, with regard to the horizontal line, as a datum or standard of comparison.

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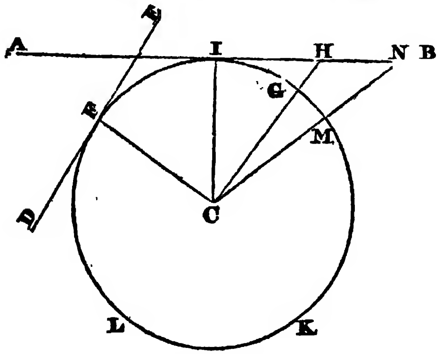
But as the earth is a globe, its circumference must be circular, as *IKL* in the annexed figure: the straight line *AB* will therefore not represent the surface of the earth, but the sensible horizon of an observer stationed

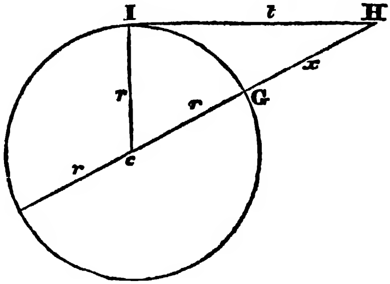


at the point *I*, to which point it is a tangent, being at right angles to the radius of the circle (or semi-diameter of the earth) *IC*. A line which is parallel to the sensible horizon of the observer, is the line traced out by our spirit-levels, and is a tangent to the earth's surface at that point only where the instrument is set up: thus *AB* is a tangent at *I*, and *DE* a tangent at *F*; such being the fact, the difference of level between any two points cannot be determined by simple reference to a horizontal line, since every point on the surface of the globe (however near to each other) has a distinct horizon of its own.

If the earth were everywhere surrounded by a fluid at rest, or that its surface was smooth, regular and uniform, every point thereon would be equally distant from the centre; but in consequence of the undulating form of the surface, places and objects are differently situated, some further from, and others nearer to, the centre of the earth, and consequently at different levels. The operation of levelling may therefore be defined as the art of finding how much higher or lower any one point is than another, or, more properly, the difference of their distances from the centre of the earth.

Referring to our last figure, we have seen that the line *AB* is a true horizontal or level line at the point *I*, but being produced in the direction *A* or *B* it rises above the earth's surface; and although it may appear to be level as seen from *I*, yet it is above the true level (which is represented by the circumference of the circle) at every other point, and continues to diverge from it, the further it is produced; at *G*, the apparent line of level, as the horizontal line *AB* is called, is above the true level, by the distance *GH*, and at *M* by the distance *MN*, the *difference being equal to the excess of the secant of the arc of distance above the radius of the earth.*

The difference GH or MN between the true and apparent level may be thus found. Put t in the following diagram for the tangent IH, r for the radius CI of the earth, and x for GH, the excess of the secant of the arc of distance above the radius; IH being considered as equal to IG; then



$$(r + x)^2 = r^2 + t^2$$
$$\text{or } r^2 + 2rx + x^2 = r^2 + t^2$$
$$\text{and } 2rx + x^2 = t^2$$
$$\text{or } (2r + x)\, x = t^2$$

But because the diameter of the earth $2r$ is so great with respect to the quantity (x) sought at all distances to which a common levelling operation usually extends, that $2r$ may be taken for $2r + x$ without sensible error; we then have

$$2rx = t^2$$
$$\text{and } x = \frac{t^2}{2r}$$

Or in words:—The difference (x) between the true and apparent level is equal to the square of the distance (t^2) divided by the diameter of the earth ($2r$), and consequently is always proportional to the square of the distance.

The mean diameter of the earth is 7916 miles, and the excess of the apparent above the true level for one mile $\frac{t^2}{2r} = \frac{1}{7916}$ of a mile, or 8·004 inches; at two miles it is four times that quantity, or 32·016 inches, and so on increasing in proportion to the square of the distance.

If we reject the decimal ·004, and assume the difference between the true and apparent level for one mile to be exactly 8 inches, or two-thirds of a foot, there arises the following convenient form for computing the correction of level due to the curvature of the earth, for distances given in miles, *viz.*, $\frac{2D^2}{3}$, D being the distance in miles.

A very easily remembered formula, derived from the above for the correction for curvature in *feet* is two-thirds of the square of the distance in *miles;* and another, for the same in *inches* is *the square of the distance in chains divided by* 800.

But the effect of the earth's curvature is modified by another cause, namely, refraction. This, as regards celestial objects, has already been explained in Part II., page 96, and is equally applicable to our present subject. The distance at which an object can be seen by the aid of refraction, is to the distance at which it could be seen without that aid, nearly as 14 to 13, the refraction augmenting the distance at which an object can be seen by about a thirteenth of itself. Hence to correct the error occasioned by refraction, it will only be requisite to diminish the effects of the earth's curvature, or height of the apparent above the true level, by one-seventh of itself.

The following Table shows the reduction of the apparent to the true level, both for the curvature of the earth only, and also for the combined effects of curvature and refraction.

Table of the Difference of the Apparent and True Level for distances in Chains.

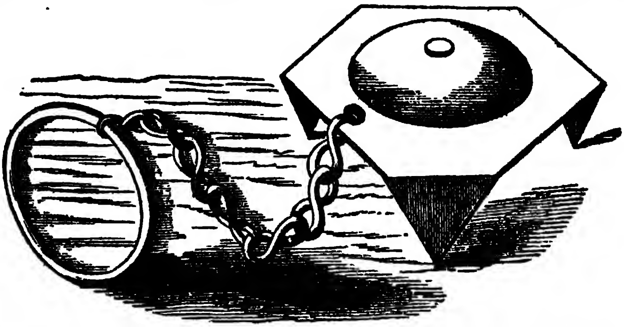
Distance in Chains.	Correction. Curvature, in decimals of feet.	Correction. Curvature and Refraction, in decimals of feet.	Distance in Chains.	Correction. Curvature, in decimals of feet.	Correction. Curvature and Refraction, in decimals of feet.
1	·000104	·000089	11	·012610	·010809
2	·000417	·000358	12	·015007	·012863
3	·000938	·000804	13	·017613	·015097
4	·001668	·001430	14	·020427	·017509
5	·002605	·002233	15	·023450	·020100
6	·003752	·003216	16	·026680	·022869
7	·005107	·004378	17	·030120	·025817
8	·006670	·005717	18	·033767	·028943
9	·008442	·007236	19	·037628	·032248
10	·010422	·008933	20	·041687	·035732

The correction for distances greater than those given in the Table may be computed by the following rule—the same by which the Table itself was computed:—

Rule.—To the arithmetical complement of the logarithm of the diameter of the earth, or 2·3788603, *add double the log. of the distance in feet, the sum will be the log. of the correction for curvature in feet and decimals; from which if one-seventh of itself be subtracted, the result will be the combined correction for curvature and refraction.*

Little dependance can however be placed upon the accuracy of any tabulated quantities on account of *terrestrial* refraction, for when near the horizon, it is unequally influenced by the variable state of the atmosphere. The rays are sometimes affected laterally, and they have been even seen convex instead of concave.

In the second part of this work, we have given a full description of the various instruments used in levelling operations, we will not

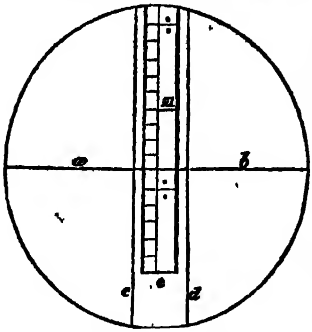


therefore revert to them here beyond making a few remarks on levelling staves, and also on an instrument of simple construction as represented in the above figure, its use being to rest the levelling staff upon when held at any station. It consists of a triangular piece of sheet iron, of about one-tenth of an inch in thickness, having the corners turned down to form the feet of the tripod, which are to be pressed into the ground by the foot of the staff-holder; a rounded piece of iron is rivetted on the upper surface, to present a clean spot to rest the staff upon when held at the station; the chain with the attached ring is for the convenience of the staff-holder in lifting it from the ground, and carrying it from station to station; by the use of the above instrument, the staff is sure to be kept on the same spot, and at the same height from the ground while the observer is reading the staves both at the back and forward station on each side of the spirit-level.

The levelling staff, a necessary accompaniment to all levelling instruments, has been heitherto always made with a sliding vane to move up and down a staff graduated to feet and decimals of feet and inches.* A description of staff has however been lately introduced by Mr. Gravatt, the face of which is made broad enough to contain sufficiently large graduations and figures, for the observer to read with certainty through the telescope of his instrument to the one-hundredth part of a foot at the distance of 12 chains or more, which is sufficient for most practical purposes, thus securing

* This was effected by a string and pulley, or the staff itself was made in two or three pieces, each of the upper pieces sliding in a groove in the one next below it. For any

greater certainty and expedition in the work. A short description of this staff has already been given at page 104, and the only care required on the part of the staff-holder in using it, is that he may hold it perpendicular. To assist him in this, a small plummet is suspended in a groove cut out in the side of the staff, by which its verticallity can be determined



in one direction, and the observer himself can detect if it be held aslant in the other direction, as may be understood from the adjoining diagram, which represents the staff *e* as it appears in the field of an inverting telescope, where *ab* represents the horizontal wire, *c* and *d* two wires placed at right angles to it, and separated so as to admit at usual distances, the staff *e* to appear between them, and by which the observer can tell if the staff-man holds it erect in a lateral direction.

Levelling staves of the above description are now generally used in India, and are manufactured in the Mathematical Instrument Department. They are better adapted for the climate than the one with vane and vernier, the staff invariably warping, and the vernier coming off, rendering the instrument for the time unserviceable. Any defect caused by the wear of Gravatt's staff can be remedied by the surveyor himself, the edges being secured by a moulding screwed on, and the face of the staff can be renewed by glueing on new strips of paper with the divisions marked on them, which, with the protection of a coat of varnish, will make the instrument again serviceable.*

From what has been said on the subject of the corrections for curvature and refraction, it is necessary to remark that such corrections are very seldom applied in practice, the observer by the arrangements of his operations doing away in a great degree with their injurious effects.

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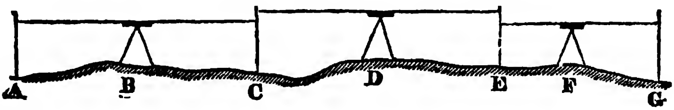
height less than the length of the first piece (generally about 6 feet) the vane was slid up or down with the hand; but for a greater height, the second piece with the vane *at the top*, was moved up bodily till the centre of the vane was cut by the line of the optical axis of the instrument, when the height was read on another scale graduated *downwards from the top* on the side of the lower joint of the staff.

* For a description of the staves now in use in the spirit-levelling operations of the Great Trigonometrical Survey of India, see Appendix—"Memorandum on Levelling Operations by Coll. J. T. Walker, R.E., etc., Superintendent, G. T. Survey;" also "Papers prepared for the use of the Thomason Civil Engineering College, Roorkee," No. VII, Chapter XIII, Article Levelling, pp. 187 to 195.

The method adopted in practice is to place the instrument as near as possible midway between the station staves, the effect of curvature is thus removed, as well as that of atmospheric refraction, as the latter will affect both observations alike, unless under peculiar circumstances of the weather, &c., over which the observer has no control. In an extended line of operations, it can however scarcely ever happen that one placing of the instrument will complete it, a succession of similar operations must therefore be performed, as shown in the annexed figure.

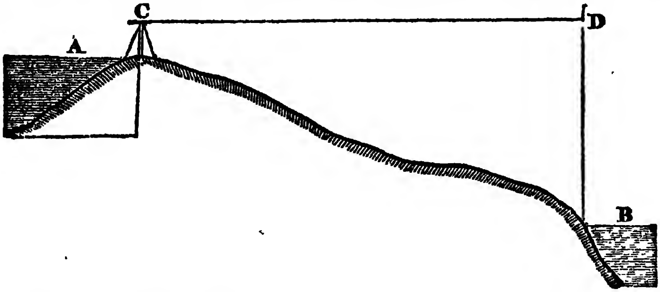


Suppose it were required to find the difference of level between the points *A* and *G*; a staff is erected at *A*, the instrument is set up at *B*, another staff at *C*, at the same distance from *B* that *B* is from *A*, and the readings of the two staves are noted. The instrument is then conveyed to *D*, and the staff which stood at *A* is now removed to *E*, the staff *C* retaining its former position, and from being the forward staff at the last observation, is now the back staff: the readings of the two staves are again noted, and the instrument removed to *F*, and the staff *C*, to the point *G*, the staff at *E* retaining the same position now becomes in its turn the back staff, and so on to the end of the work, which may thus be extended many miles: the difference of any two of the readings will show the difference of level between the places of the back and forward staff; and the difference between the sum of the back sights, and the sum of the forward sights will give the difference of level between the extreme points, thus:

	Back Sights.		*Fore Sights.*
	Ft. Dec.		*Ft. Dec.*
A, and *C*,	10·46	—	11·20
C, „ *E*,	11·33	—	8·00
E, „ *G*,	7·42	—	7·91
Sums	29·21	—	27·11
	27·11		
Difference of level	2·10		

showing that the point *G* is 2 feet and $\frac{10}{100}$ higher than the point *A*.

The foregoing process is called compound levelling. The following is an example of simple levelling, being performed at one operation, and therefore subject to the correction for curvature and refraction to obtain a correct result.



If it were required to drain a Jheel *A*, by making a cut to a stream at *B*, a distance of 20 chains: let a level be set up at *C*, and directed to a staff held upright at the edge of the water at *B*. The horizontal line *CD* represents the line of sight which would cut the staff at *D*, the reading being 17·44 feet; the height of the instrument above the ground was 4 feet, and the depth of the Jheel 10 feet; therefore the difference of level between the bottom of the Jheel and the surface of the stream was as follows:

		Ft. Dec.
Reading of the staff		17·44
Height of instrument	4·00	
Depth of Jheel	10·00	
Curvature and Refraction for 20 Chs., see Table, page 539	0·03	
		14·03
Difference of level		3·41

The following will explain the method to be pursued in levelling a tract of country.

In the first instance the staff-holder must place his staff on the Bench mark* from whence the levels are to commence. The surveyor must then set up his spirit-level in the most suitable spot which presents itself, from whence he can have an uninterrupted view, not only of the staff at the back station, but also for a considerable distance in the direction he wishes to carry his levels. The station selected should not in any case

* In the practice of levelling, it is usual to leave at convenient intervals, what are called *Bench marks*; these mostly consist of permanent objects, such as milestones, curbstones of bridges, mosques, masonry houses, wells, and sometimes the stumps of old trees, etc., on which it is usual to cut a distinguishing mark, that it may be known hereafter. Their use is chiefly for future reference, in the event of its being necessary, either to check the levels by repetition, to change the direction of the line of levels from any point, or to take up and continue the levels at the commencement of a day's work, a Bench mark having been left at the close of the day preceding.

exceed 4 or 5 chains, for when long distances are taken, unless both the back and forward stations are equally distant from the instrument, errors will gradually creep in, which, in a long series of levels, are liable, by their accumulation, to be of serious consequence.

The proper station being determined on, and the level adjusted for observation,* it must be directed to the back staff, and the foot and decimal fraction of a foot, with which the central part of the horizontal wire appears to be coincident, noted with all possible exactness, and entered in the proper column of the Field or Observation Book; as soon as it is registered, look to see that the spirit bubble has not returned from its central position, and then repeat the observation, to ensure that no mistake has been made in noting it.

The back observation being made, turn the telescope round in the forward direction; then look at the spirit bubble, and if it has at all changed its position, by receding towards either end of the tube, bring it back to the centre by the parallel plate screws; then observe what division on the staff is intersected by the cross-wire, and enter the reading in the proper column of the Field-book. Having entered it, verify it by a second observation, which will complete the first levels. The first levels being completed, the surveyor, passing the man who holds the forward staff, proceeds to some convenient spot to set the instrument a second time, which, as before remarked, should not be more than 4 or 5 chains distant; the man who held the staff at the back station, likewise proceeds still further onwards to take up a new station, and as nearly as possible at the same distance from the instrument as the instrument is from the staff which has now become the back station. The instrument is then again adjusted, and the same process followed as above described, until arrived at the end of the series.

The foregoing description of the method of taking levels is general, and applies equally to every kind of levelling operation.

* The Level must be adjusted for observation in the following order: First draw out the eye-piece of the Telescope till the cross-wires are perfectly defined; then, directing it to the staff, turn the milled-headed screw A (see figure, page 99) on the side of the Telescope, till the smallest graduations on the staff are likewise clearly distinguishable; that these two adjustments be very carefully and completely performed is of more consequence than is generally supposed, for upon them depends the existence or non-existence of parallax, to remove which has already been explained at pages 101 and 102. The above adjustments being made perfect, bring the spirit bubble into the centre of its glass tube, and which position it must retain unmoved in every direction of the instrument; this is accomplished in the same manner as in the Theodolite by bringing the Telescope successively over each pair of the parallel plate-screws, and giving them motion, screwing up one, while unscrewing the other to an equal extent.

The following is the form of Field-book used for entering the observations, &c. :—

*Form of Field-book for Observations.**

No. of Station.	Back Level.	Back Bearing.	Back Distance.	Height of Instrument.	Fore Bearing.	Fore Distance.	Fore Level.	From 1st Station in the Series. Rise.	From 1st Station in the Series. Fall.	Results. Rise.	Results. Fall.	Remarks.
	Ft. Dec.	° ′	Ch. Lks.	Ft. Dec	° ′	Ch Lks.	Ft. Dec	Ft. Dec.	Ft. Dec.	Ft. Dec.	Ft. Dec.	
1	13·71	205·30	5·19	3·40	25·20	7·96	7·88	5·83	...	5·83	...	Commenced from bench mark on Tal Tree, N. E., corner of Mundulpore Tank, 100 feet above datum.
2	9·40	208·15	2·27	3·60	25·10	3·08	16·30	...	1·07	...	6·90	
3	3·87	207·10	5 08	3·70	23·20	3·40	11·71	...	8·91	...	7·84	
4	2·63	206·40	6·59	3·70	28·25	4·00	12·41	...	18·69	...	9·78	
5	14·62	205·10	3·92	3·80	26·15	5·20	0·95	...	5·02	13·67	..	
6	17·00	208·30	4·64	3·95	29·30	3·89	1·45	10·53	...	15·55	...	

Where levels are made for the formation of a section, it is necessary that the distance between the levelling staves be measured, as well as the bearing observed of each staff to enable the surveyor to plot and draw the section; but in running or check levels there is no necessity for the chain or compass, the object of check levels being only to obtain the difference of level between certain intermediate and the extreme points of the section previously made, to check its accuracy. It is also immaterial by what route we proceed from one point to another, so that such spots may be selected for the stations as are most convenient for the purpose, and may afford opportunity of checking any intermediate points on the section line. The Field-book required therefore for check levels is merely a simple entry of back and fore sights, the difference of the sums of which will be the difference of level between the extreme points of the section line.

Form of Field-book for Check Levels.

Stations.	Back Sights.	Fore Sights.	Remarks.
	Feet	Feet	
1	4·19	4·24	Back station on bench mark at milestone 72.
2	5·44	1·20	
3	4·96	3·20	
4	4·73	1·32	Forward station top of milestone 87.
	19·32	9·96	Sums.
	9·96		
	9·36	Difference.	

* See also "Memoranda on Levelling Operations," by Coll. J. T. Walker, R.E., &c., &c., given in the Appendix.

Datum Line.

It is usual to refer all levels to a certain datum line previously fixed, and in the course of a long series of levels, to keep a register of the heights of particular spots above this given datum, which may be considered as so many zero or fixed points easily recognizable if carefully noted in the Field-book, and from whence any portion of the work can be levelled over again, or branch lines of level be conducted in any direction, and the levels of such branches be comparable with those of the main line.

This datum line should invariably be assumed from some known and fixed *permanent* point, which may always be referred to without the chance of doubt and misconception at any subsequent period. For instance, the recent levels of the town of Calcutta, taken by Mr. Simms, the Consulting Civil Engineer to Government, are all calculated from the bottom or sill of the stone on the Tide Gauge at Kyd's Dockyard, a point which must always be easy of ascertainment, and which is peculiarly convenient for comparison with the mean level of the sea.

This point of the Tide Gauge has been ascertained to be 8·38 feet *below* the sea level, by a series of observations of the heights of the tides at Calcutta at high and low water, from which the lowest monthly average of the mean tidal level in the months of February and March has been assumed as the mean level of the sea.

The observations made for this purpose tend to show that the locality of Calcutta is unfavorable for determining with great precision the mean sea level, owing perhaps to the length of the channel which the tides have to traverse, and the great effect produced by the rise of the river in the monsoons, the difference of the mean height in the month of September being 6¼ feet above that of February or March.

But these disturbing causes are, for the most part, independent of the influence of the sea itself, the monthly mean tide of which should be an uniform quantity, affected only to a slight degree by the pressure of the wind. Divested of these anomalies it may be concluded that the mean state of the water in the river can never be *lower* than the actual sea level, the lowest monthly average of mean tide is therefore perhaps the nearest approximation to the truth.

According to these levels, the surface of the mercury in the cistern of the Standard Barometer in the Calcutta Observatory* is 18·21 feet, and

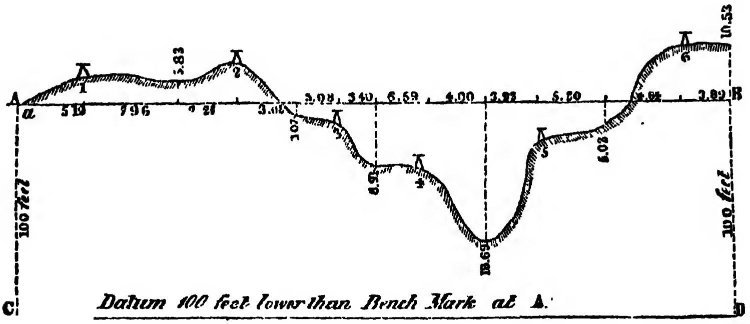
* The *old* Observatory, No. 19, Chowringhee Road, formerly Board of Revenue Office, is here alluded to. The present Observatory, or *make-shift* for one, is situated at No. (new) 46 Park-Street, the Surveyor General's Office, where it originally stood.

the floor of the large puckha Ghat, inscribed to Lord William Bentinck and known as "Baboo's Ghat," exactly 17·79 feet *above* the mean level of the sea.*

Plotting Sections.

When a line of levels of any considerable length is to be plotted, the horizontal distances cannot be laid down on as large a scale as is necessary for the vertical heights above the datum point, in order that the section may be of any practical use, without making the plot of most unwieldy dimensions. It is therefore usual to make the vertical scale much larger than the horizontal one: thus 4 inches to a mile for the horizontal distances, with 1 inch to 100 feet for the vertical distances, is an usual combination; the vertical scale being so much greater than the horizontal, shows the depths of cutting and embankment required in the execution of roads, railways, canals, &c., with greater clearness than if both scales were equal.

For instance, to plot the line of levels as given in the Field-book, page 545.



Draw a line AB representing the horizontal line as the datum to which the levels are reduced, as shown in the column headed "From 1st Station in the series;" assume any point a as the starting point, from which set off the measured distances as given in the back and fore distance columns; at these several points raise perpendiculars, and on them lay off the differences of level from the 1st in the series; join these several points, and the section is completed.

* The Datum Line for the Great Trigonometrical Survey Levelling is the mean sea level at Manora Harbour, Karachi (Sindh). *Manora Bench Mark*, Latitude 24° 47′ 51″, Longitude 67° 1′ 5″, is 9·30 feet above mean sea level. Calcutta Mint Bench Mark is 17·96 feet above mean sea level. Kidderpore Dock Sill is 6·25 feet below mean sea level, *vide* Great Trigonometrical Survey Table of Heights in Sindh, the Punjab, N. W. Provinces, Central India and Bengal (published in 1863 and 1866).

The section being 100 feet above the previously fixed datum point, all that is required to represent this, is to draw a line *CD*, parallel to *AB*, at 100 feet below it, then by drawing perpendiculars from the surface line to this new datum, as shown by the dotted lines, the transfer will be complete, as the heights of any points can be measured by the scale of the section. In plotting sections, it is the *horizontal* distances between the several stations that must be laid down. When the ground rises and falls in long regular slopes, the measurement, as taken along the slopes, must be reduced to horizontal distances by calculation. If the rise or fall is but slight, this reduction may be altogether disregarded, the difference between the horizontal and hypothenusal measurements not exceeding the limits of error in the measure itself.

The following Table, showing the reduction to be made on each chain's length, will assist in making the necessary calculation.

Levelling with Theodolite.

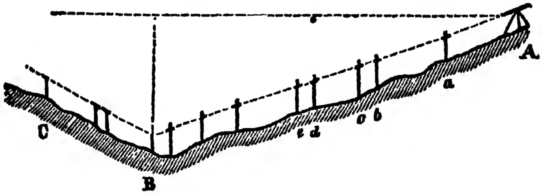
The application of the Theodolite to the practice of levelling is an operation of great simplicity.

The instrument is set up at one extremity of the line previously marked out by bandroles (small flags) or long pickets at every change of the general inclination of the ground; and a levelling-staff, with the vane set to the exact height of the optical axis of the Telescope, being sent to the first of these marks, its angle of depression or elevation is taken, and by way of insuring accuracy, the instrument and staff are then made to change places, and the vertical arc being clamped to the *mean of the two readings*, the cross-wires are again made to bisect the vane. The distances may either be chained before the angles are observed, marks being left at every irregularity on the surface where the levelling-staff is required to be placed; or both operations may be performed at the same time, the vane on the staff being raised or lowered till it is bisected by the wires of the Telescope, and the height on the staff noted at each place.

Rise in feet for one chain.	Reduction upon one chain in links and decimals.
1	0·01
2	0·04
3	0·11
4	0·19
5	0·29
6	0·44
7	0·56
8	0·74
9	0·94
10	1·16
11	1·40
12	1·76
13	2·01
14	2·24
15	2·61
16	2·99
17	3·39
18	3·76
19	4·23
20	4·64

The accompanying sketch explains this method:—*A* and *B* are the places of the instrument, and of the first station on the line, where a mark equal to the height of the instrument is set up; between these points the intermediate positions, *a, b, c, d,* for putting up the levelling-staff, are determined by the irregularities of the ground. The angle of

depression to *B* is observed, and if great accuracy is required, the mean of this and the reciprocal angle of elevation from *B* to *A* is taken, and



the vertical arc being clamped to this angle, the Telescope is again made to bisect the vane at *B*. On arriving at *B*, after reading the height of the vane at *a*, *b*, *c*, &c., and measuring the ditances *A a*, &c., the instrument must be brought forward, and the angle of elevation taken to *C*, the same process being repeated to obtain the outline of the ground between *B* and *C*. In laying the section down upon paper, a horizontal line being drawn, the angles of elevation and depression can be protracted, and the distances laid down on these lines; the respective height of the vane on each staff being then laid off from these points in a *vertical direction*, will give the points *a*, *b*, *c*, &c., marking the outline of the ground. A more correct way of course is to calculate the difference of level between the stations, which is the *sine* of the angle of depression or elevation to the hypothenusal distance *AB* considered as radius, allowing in long distances for curvature and refraction.

Instead of only taking the single angle of depression to the distant Station *B*, and noting the heights of the vane at the intermediate Stations, *a*, *b*, *c*, &c., angles may be taken to mark the same height as the instrument set up at *each of these intermediate points*, which will equally afford data for laying down the section; but the former method is certainly preferable.

The details may be kept in the form of a Field-book, but for this species of levelling the measured distances and vertical heights can be written without confusion on a diagram, leaving the corrections for refraction and curvature (when necessary) to be applied when the section is plotted.

Where a number of cross sections are required, the Theodolite is particularly useful, as so many can be taken without moving the instrument. It is also well adapted for *trial sections*, where minute accuracy is not looked for, but where economy, both of time and money, is an object.

The Theodolite is likewise used in running *check levels*, to test the accuracy of those *taken in detail with a spirit-level.* Reciprocal angles

of elevation and depression, taken between bench marks, whose distances from each other are known, afford a proof of the general accuracy of the work: and if these points of reference are proved to be correct, it may safely be inferred that the intermediate work is so likewise.

For the rigorous procedure adopted in the Levelling Operations of the Great Trigonometrical Survey of India, see Memoranda by Coll. J. T. Walker, R.E., &c., in the Appendix.

With the object of rendering the large-scale Maps of the Revenue Survey of India generally useful for engineering purposes, such as the construction of irrigation works, main canals, railway projects, new roads, &c., lines of levels are run at distances of from 1 to 2 miles apart; and in connection with these operations, rules for the guidance of surveyors are given in the "Handbook of the Departmental and Circular Orders and Instructions of the Revenue Survey Department, India," published under the authority of Government, Calcutta, 1873.

CHAPTER XI.

Contouring.

Another species of levelling to be described is that by which certain data are given, from which the outline of a horizontal section of the ground can be constructed, and is called "Contouring," a term which is applied to the outline of any figure, and consequently to that of any section of a solid body; but when used in connection with the forms of ground or of works of defence, the outline of a horizontal section of the ground, or works, is alone to be understood by it.

Contour lines give a most perfect delineation of the ground, and they are the only part of a survey which will remain unaltered in the lapse of ages, hills and valleys being much more permanent things than houses, roads and boundaries, which cease to give accurate information in a few years, and require revision at a great cost.

It would be useless expense to increase the number of Contour lines on mountain ground where no probable demand either for roads or drains exists; and on the other hand, in districts which are nearly level, Contours only at great difference of altitude would be of little practical utility.

In waste lands, Contours tend to a knowledge of the best mode of improvement, as the levels are connected with each other throughout the country, and referred to the sea as a datum line. As a general system, however, Contouring can scarcely be said to be applicable to India, where the mountains are inaccessible and for the most part untrodden, and the wastes impenetrable and impervious, from the denseness of the jungle and rankness of the vegetation. The undulations and round smooth downs of England are here wanting, and the vast extent of the country leaving but few points fixed by the great triangulation; the operation, so simple on the Ordnance Survey of England, would be one of much difficulty in this country, where there is so little to mark the inequalities of the surface until the stupendous hills rise suddenly and precipitously above the general level.*

A few remarks on the system, however, which has become so common in England, are necessary.

"The method of tracing these Contours in the field is thus performed. Bandroles or long pickets are first driven, one at the top and another at

* "The Contouring on the Ordnance Survey of Scotland has been set aside, on the recommendation of a Committee of the House of Commons, by the advice of the first Engineers in England."—*Vide* Article in the Edinburgh Review on the Ordnance Survey of Scotland.

the bottom of such slopes as best define the ground, particularly the ridge lines and watercourses; should no such *sensible* lines exist, they must be placed at about equal intervals apart, regulated by the degree of minutiæ required, and the variety in the undulations of the surface of the ground. A short picket being driven on the level of the intended upper (or lower) line of Contours, and in line between two of the bandroles, the level is placed so as to command the best general view of this first line and adjusted, care being taken that its axis is not so low as to cut the ground below the picket (or so high as to be above the top of the leveling-staff, if the lower Contour is the first traced); the staff is then placed at this picket, and the vane raised or lowered till it is intersected by the cross-wires of the Telescope; the staff is then shifted to another point on about the same level, and in the line between the next two pickets, and the staff itself moved up or down the slope till the vane again coincides with the cross-wires, at which spot another picket is driven. This operation is continued, till it is necessary to move the level to continue the same upper Contour lines, when (the staff being placed at one of the pickets just driven) the vane is again raised or lowered to suit the next position of the axis of the instrument, and kept at this height, as before, for the continuation of the line. To trace the next lower Contour line, it is merely necessary to raise the *vane* on the staff, five, ten, or whatever number of feet may be the vertical distance determined upon, and proceed as before. When the level itself has to be moved to lower ground, it must be so placed that its axis will cut the ground above one of the pickets of the line just marked out, and the same quantity of five or ten feet added to the reading of the staff at this picket will give the height of the vane for the next lower horizontal line.

"The use of driving all these pickets, marking out the Contours nearly in the same line down the slopes, becomes evident when they are to be laid down on the plan, the places of the original bandroles or long pickets being fixed with reference to each other, it is only necessary to measure between them, entering the distances on these lines, with the offsets to the right or left to the different short pickets marking the horizontal lines."*

* The instrument, best adapted for Contouring where a rapid delineation of country is an object frequently of greater importance than accuracy, is the *water-level*, its best recommendation being the facility with which it can be made, and requiring no adjustment when using it. The following description is taken from "Frome on Trigonometrical Surveying:"

The French *water-level* is much used on the Continent in taking sections for military purposes. It possesses the great advantage of *never requiring any adjustment*, and does not cost the one-twentieth part of the price of a spirit-level. From having no Telescope,

"Contoured plans, from which sections are to be constructed, are generally plotted on about the same scale as special surveys of estates, that is, on one of 2, 3, or 4 chains to one inch. Small portions of ground for military purposes, where the vertical distances are under five feet, may even be laid down on a scale of one chain to one inch."*

The method adopted in carrying on the Contours of the Ordnance Survey of England is detailed in the following memorandum obtained

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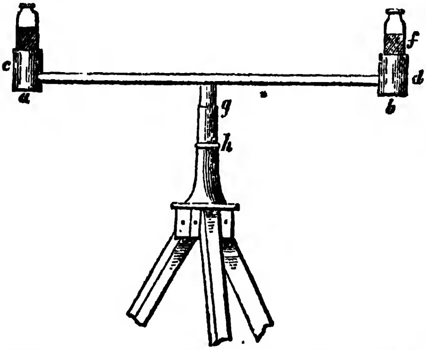
it is impossible to take long sights with this instrument; and it is not of course susceptible of *very minute accuracy:* but, on the other hand, no gross errors can creep into the section, as may be the case with a badly adjusted spirit-level, or a Theodolite used as such, the horizontal line being adjusted by nature without the intervention of any mechanical contrivance. As this species of level is not generally known in England, the following description is given, which, with the assistance of the sketch, will enable any person to construct one for himself without further aid than that of common workmen to be found in every village.



a b is a hollow tube of brass about half an inch in diameter, and about three feet long, *c* and *d* are short pieces of brass tube of larger diameter into which the long tube is soldered, and are for the purpose of receiving the two small bottles *e* and *f*, the ends of which, after the bottoms have been cut off by tying a piece of string round them when heated, are fixed in their positions with putty or white lead —the projecting short axis *g* works (in the instrument from which the sketch was taken) in a hollow brass cylinder *h*, which forms the top of a stand used for observing with a repeating circle; but it may be made in a variety of ways so as to revolve on any light portable stand. The tube, when required for use, is filled with water (coloured with lake or indigo), till it nearly reaches to the necks of the bottles, which are then corked for the convenience of carriage. On setting the stand tolerably level by the eye, these corks are both withdrawn (which must be done carefully and when the tube is nearly level, or the water will be ejected with violence) and the surface of the water in the bottles being necessarily on the same level, gives a horizontal line in whatever direction the tube is turned, by which the vane of the leveling-staff is adjusted. A sight could easily be attached to the outside of *c* and *d*, by which the intersection of two cross-wires could be made to coincide with the surface of the water in each of the bottles; or floats, with cross hairs made to rest on the surface of the fluid in each bottle, the accuracy of their intersection being proved by changing the floats from one bottle to the other; either of these contrivances would render the instrument more accurate as to the determination of the horizontal line of sight; though one of its great merits, quickness of execution, would be impaired by the first, and its simplicity affected by either of them. For detailed sections on rough ground, where the staff is set up at *short distances apart*, it is well qualified to supersede the spirit-level; and is particularly adapted to tracing *Contour lines.*

* Frome on Trigonometrical Surveying.

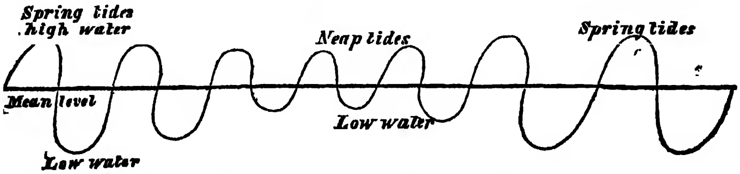
from the Ordnance Map Office at Southampton, and which gives a clear explanation of the subject:

"By the aid of Contours we obtain such a perfect knowledge of the configuration of the country, that every map may be said to be a model of the district, and their advantage increases in proportion as the area to be examined is extended.

"The Contour lines are formed by connecting points of equal altitude determined by levelling, and traced through any district; they are placed at equal altitudes above each other as at 25, 50, 100 feet, &c., depending upon the nature of the country, and these are taken above a given datum level.

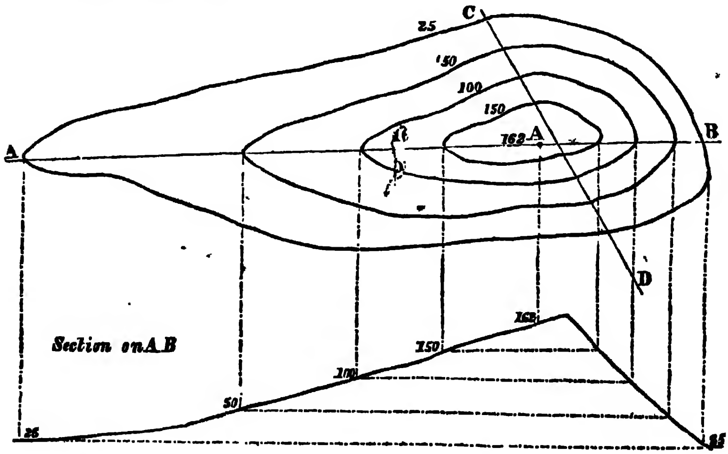
"The mean level of the sea is found to be a more constant level round this kingdom.

"The tides from the springs to the neaps may be said to oscillate above and below the mean tidal line, and it is found that although the rise and fall of the tides varies in amount round the coast, the mean



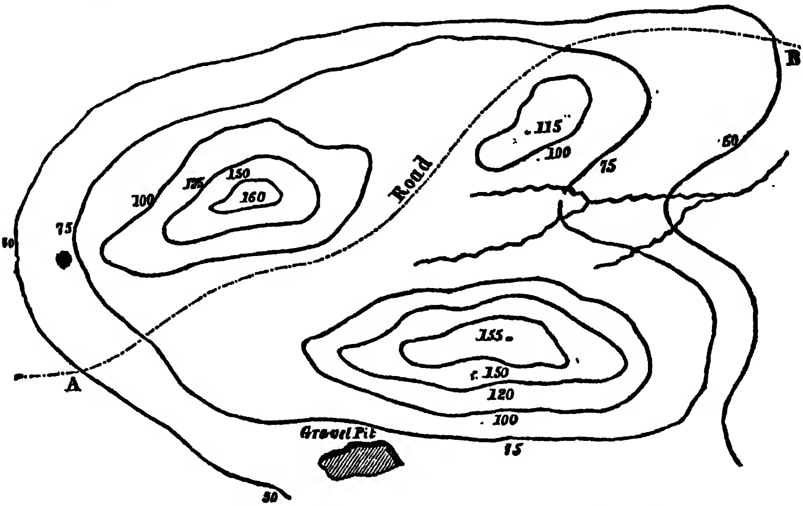
tidal line is nearly a constant level, and it is therefore a much better line of reference for the Contours than any other.

"To illustrate the principles of Contouring, first take as an example an isolated hill or an island, and the section in any other direction as *CD* can be given at once.



"Take an example of a supposed more extensive district, and that other Contours are interpolated by the eye, which can be done with great accuracy where there is so much fixed data.

"The line which a road should take from *A* to *B* may be determined better in the closet than on the ground, and without having reference to local surveys made too frequently under the dictation of local influence to obtain a particular object, and in disregard of the interests of the community who have to pay for the construction and maintenance of the road.



Contouring.

"The Contouring on the Ordnance Survey is divided into six branches, viz.:

1, Initial levelling; 2, Road and Trigonometrical line levelling; 3, The Contouring; 4, Plotting; 5, Examining; 6, Hill Sketching.

Initial levelling.

"The initial levelling is the first operation, and is the basis of all the rest. It consists in levelling with a superior instrument the main roads in any district of country leaving permanent marks (either copper bolts or bench marks on masonry), the value of which, in altitude, is most accurately fixed by twice or even three times levelling. The work is kept in Field-books, and the leveller makes a survey of the road as he works, in order that the position of the marks and altitudes may be correctly plotted on the plans when made. The instruments used on the survey are 12-inch spirit-levels.

"This levelling has been carried on to a considerable extent in England and Scotland, and is much in advance of the Contouring.

2nd. "Road and trigonometrical line levelling for Contour purposes is built upon the initial levelling, and depends upon it.

Road and trigonometrical levelling.

"The books of the initial levelling having been worked out at the map office, a correct list of the marks and their values is furnished to the district office for any district required to be contoured.

"This district is then carefully perambulated, and such roads as pass over important features of ground are levelled with a second rate instrument (a 10-inch or 5-inch Theodolite). As it is found that roads generally keep to the valleys, and are not so useful for contouring purposes when levelled as lines at right angles to the general run of Contours, recourse is had to trigonometrical line levelling, that is to say, lines of levels are run from one trigonometrical station to another, crossing the general run of Contours at right angles as nearly as possible.

"Sometimes a road may be found that goes directly up a hill, and then it is invariably used for levelling purposes in preference to a trigonometrical line, on account of the facility in working on it compared to levelling in fields; wooden pickets are left along these lines wherever there is no means of making a bench mark on masonry, and the values given in levelling have reference to the tops of these pickets. This Contour levelling depends upon the initial road levelling, inasmuch as it starts from some mark on one initial line, and closes on some other mark.

3rd. "The non-commissioned officer in charge of a section of Contourers, has a list given him of the marks in the district he is employed upon; when he requires any particular Contour line laid down, he furnishes the party who is to do it with the position and value of the nearest mark to the required altitude on a levelled line; this is used for a starting point, and having risen or fallen from this mark till he has obtained the Contour height, he proceeds to lay out the Contour line by rods fixed in the ground as a temporary mark; at the same time he surveys the position of these rods with reference to the detail shown on a plan furnished to him, and enters the survey in a Field-book.

Contouring.

"At certain convenient places on his Contour line he leaves wooden pickets, which enable his work to be tested afterwards, and he continues this operation till he comes across some levelled line, the position of which with the marks is shown on his plan. He levels up or down (as the case may be) from his Contour to the nearest bench mark on this levelled line, and finds the difference in altitude between them, which difference he takes to the non-commissioned officer, who, knowing the value of the

bench mark closed upon, is able to tell whether the Contour is correct at the close.

"If in a flat country an error is manifest of two or three-tenths of a foot, the Contour is run again, but in a moderate country half a foot is allowed to pass; no Contour is allowed to go much beyond four or five miles without a check of this kind.

Plotting.

4th. "The Field-books and plans being sent in, the work is plotted on the engraved sheets; the bench marks on the levelled lines being also plotted, and the position of the wooden pickets left by the Contourer shown, one sheet is sent in this state to the examiner for examination.

Examining.

5th. "Who is directed to walk every Contour line in order to see whether the plotting is correctly done, and to fill in all omissions arising from incorrect referencing of the Contour Field-books, &c., also to re-contour whatever is doubtful, and to check a fair number of the Contours, by levelling from some permanent mark to one or more of the wooden pickets left by the Contourer. The examiner sends his documents into the office when all the corrections are made on the fair plan, and all the fresh values in altitude obtained from the examiner's levelling inserted.

Hill Sketching.

6th. "The hill sketching is carried on in a much more rapid manner by two men, one with an instrument and the other with a light levelling staff. The latter has the plan with all the instrumental Contours shown on it, and he is placed by the assistant on the intermediate 25 feet Contour lines, the outline of which he sketches in on his plan until the whole is completed,—this work is not kept in Field-books.

"The instrumental Contours hitherto run have been the 25 feet—50—100—150—200—250—300—350—400—500—600—800—1000—1200—1400—&c., &c.,

"Whilst the Contours interpolated have been the 75 feet—125—175—225—275—325—375—425—450—475—525—550—575—625—650—675—700—725—750—775—825—850—875—900—925—950—975—1025—1050—&c., &c."

In further elucidation of this subject, see the article in the Aide Mémoire to the Military Sciences, Vol. I, page 227; also article "Field Sketching" in the same work, Vol. I, page 518. See also Frome's Trigonometrical Surveying, &c., 4th edition, revised and enlarged by Capt. C. Warren, R.E., &c. (London, Lockwood & Co., 1873) article "Contours," pp. 102 to 108.

Part V.

CHAPTER I.

Practical Astronomy, and its Application to Surveying.

Definitions.

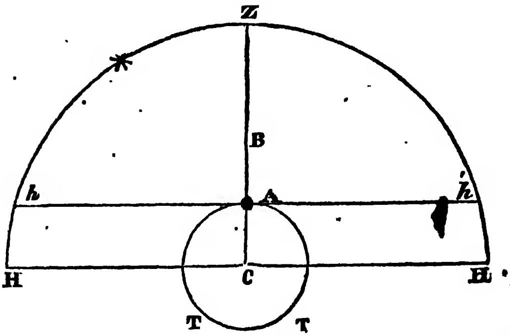
Suppose a plummet to be freely suspended from a given height, it will fall perpendicularly upon the surface of a pool of stagnant water, for there is no reason to believe that it should be more inclined to one side than to another.

Now, conceive the line wherewith the plummet is hung to be produced to the heavens, it will cut a point there, which is called the zenith.

Again, if the surface of the stagnant water be imagined to be extended as far as the heavens, it will form a plane, which, with reference to a spectator placed where the plummet was supposed to be suspended, will divide the visible from the invisible part of the heavens. This plane is called the sensible horizon.

Again, conceive another plane to be drawn through the centre of the earth parallel to the sensible horizon, it will be the spectator's rational horizon or simply horizon.

In the annexed diagram ATT_1 represents the earth, C being its centre.



Now let BA be the direction of the plummet at any point A on the earth's surface; the line AB, produced to the heavens will furnish Z the zenith. Again the plane hAh' drawn perpendicular to the zenith line AZ, will be the sensible horizon, being coincident with the surface of the stagnant water at A; while the plane HCH' drawn parallel thereto through the earth's centre, will be the rational horizon.

In Astronomy, all measurements made on the surface of the earth, are referred to its centre or to the rational horizon HCH'. This subject has already been adverted to at page 95, on reference to which, it will be seen, that the correction whereby an observation is transferred to the

earth's centre, is called "parallax." This parallax is always of small amount, being the angle subtended by the earth's semidiameter at the object observed. The sun, the moon, and the planets are the only celestial bodies which are liable to this correction, the stars being free from it, owing to their immense distance from the earth. In the Appendix, will be found a Table of Parallax for the sun. Here it is only necessary to observe that it will be convenient to throw the sensible horizon out of consideration altogether, and supposing the observer or rather his eye to be placed at the earth's centre, refer the definitions of the Astronomical terms to that point at once.

To a spectator situated at the earth's centre, the heavens will appear like a sphere of which his eye will be the centre, the stars being placed or projected on its interior surface. This being admitted, it will follow from what is said at page 336 of this work, that the rational horizon is a great, and the sensible horizon a small circle of this celestial sphere.

Now, extend the zenith line ZA, until it meets the rational horizon HCH'. This junction would have taken place at the centre C, if the earth were a sphere. But as this, however, is not the case (the earth being a spheroid, differing in a small degree from a sphere) the junction above adverted to will occur at a small distance from the centre. Considering the nature of the computations which will be treated of in this treatise, no sensible error need be apprehended if the earth is taken as a sphere, and we will accordingly make this assumption, in which case it is clear, that the earth's centre C will become the site at which the zenith line AZ produced will meet the rational horizon HCH' as represented in the figure.

Suppose a plane to be drawn through the zenith line CZ and extended to the heavens, this will be a vertical plane, and there are four properties belonging to it, which are as follow :—

1st. It will be perpendicular to the rational horizon.

2nd. It will always pass through the zenith.

3rd. It may be drawn through any given point; and

4th. The figure which it will trace on the interior surface of the celestial sphere, will be a great circle of that sphere.

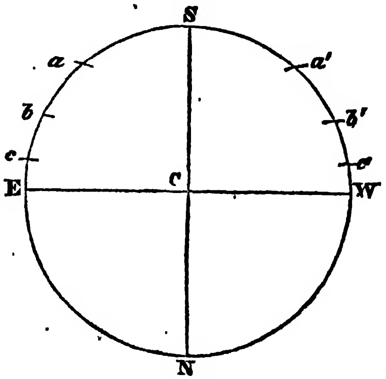
A circle formed in this way, by the section of a vertical plane with the celestial sphere, is called a vertical circle.

To illustrate these definitions, we will suppose that in lieu of the spectator, a theodolite is placed at the earth's centre, duly levelled and adjusted. It is evident that the azimuth circle will become coincident with the rational horizon, and that the telescope, when moved round in altitude, will describe a vertical circle in the heavens.

Altitudes and zenith distances are measured upon vertical circles. For instance, supposing a vertical circle to be drawn through an object, its altitude will be that part of the vertical circle intercepted between it and the horizon. Again, the zenith distance of the object in question is an arc of the same vertical circle lying between it and the zenith.

The zenith being 90° from the horizon, it follows that when the altitude and the zenith distance of an object are added together, the sum will amount to a quadrant. Hence one of these elements being known, the other may be found by deducting the given term from a quadrant or 90°.

We will now attend to the phenomena of the rising and setting of stars. With this view let the annexed circle represent the plane of the rational horizon, *C* being its centre, which is coincident with the centre of the earth. Suppose, a spectator, placed at this centre with his face turned towards south, observe a star to rise at *a* and set at *a′*. Again, let him in a similar manner mark the points *b* and *b′* of the rising and setting of another star. Now the horizontal arcs *a a′* and *b b′* being bisectable at one point, let this point be *S*. The point *S*, so found, is called the South point of the horizon.



Suppose now a vertical circle to be drawn through *S*, it will be the meridian of the place to which the rational horizon, adverted to above, appertains. Like every other vertical circle the meridian will pass through the zenith, and be perpendicular to the horizon. In addition to these properties, it will have this peculiarity, namely, that it will be the locus or the line of the greatest altitudes which stars attain to during the day.

An altitude, measured on the meridian, is called the meridional altitude, in contradistinction to altitudes observed upon other vertical circles.

As stated elsewhere, the meridian cuts the horizon at the south point or *S*. It will likewise intersect it at another point *N*, which is called the North point of the horizon.

If a vertical circle be drawn perpendicular to the meridian, it will be the prime vertical. Like the meridian the prime vertical will intersect the horizon at two points, which will be the East and West points of the horizon.

In the preceding diagram, the lines *NS* and *EW* represent the projections, the former of the meridian, and the latter of the prime vertical upon the plane of the horizon; the points *N*, *S*, *E*, and *W* standing for the four cardinal points, *N* for north, *S* for south, *E* for east, and *W* for west.

The azimuth of an object is measured upon the plane of the horizon. For instance, take any star, and suppose a vertical circle to pass through it, the arc of the horizon intercepted between the north and the vertical circle aforesaid, is called the star's azimuth.

"We have spoken of the risings and settings of stars, such as they will appear to be to a spectator placed at *C*, the centre of the plane of the horizon, but hitherto we have said nothing of the intervals of time elapsed between their respective risings and settings. Now, a spectator, in the northern climate, looking towards *S*, the south, cannot fail to remark that a star between its rising at *b* and setting at *b'* is longer above the horizon than a star which rises at *a* and sets at *a'*, which kind of inequality takes place, and in a greater degree with every star successively placed between *b* and *S*. But he may also note, that every star takes the same time in passing from its rising through its setting to its rising again. A star, therefore, at *a* is longer below the horizon than a star at *b*, and still much longer than a star at *c*. But a star rising at E, the east point, has this peculiarity, namely, that it is above the horizon exactly as long as it is below. On this account, the circle in which such a star moves, is called the Equator.*

The equator, traced in the way described above, will be a great circle of the celestial sphere, perpendicular to the meridian and cutting the horizon at the points *E* and *W*. Imagine now a line to be drawn from *C* perpendicular to the plane of the equator, it will, when produced northward and southward, point to the North and the South Poles. This line is called the axis of the celestial sphere.

Besides the zenith and the north and south points upon the horizon, the meridian of a place will pass through the North and South Poles of the celestial sphere.

The axis of the celestial sphere coincides with the earth's axis of rotation. Again the planes of the terrestrial equator and meridian, as laid down at page 336, when extended, will trace on the interior surface of the celestial sphere the Equator and meridian defined in this chapter.

There are two co-ordinates required to determine the position of a

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* Woodhouse's Astronomy, Vol. I., part i., page 6.

star in the heavens, namely, 1st, the *declination*, and 2nd, the *right ascension.* The simplest definitions, which can be given of these terms, are as follow:—Suppose the given star to transit, or come to the meridian, then its *declination* will be the arc of the meridian intercepted between the star and the equator, its right ascension being the time which would be shown by a siderial clock adjusted to read $\overset{h.}{0}\ \overset{m.}{0}\ \overset{s.}{0}$ when the first point of Aries passed the meridian.

The first point of Aries may be determined in this way. It is well known that either on the 20th or 21st March, the day and night are equal or nearly so; or which is the same thing, the sun remains as long above the horizon as below it. On the day that this equality takes place, the sun rises due east and sets due west: or in other words, it occupies a point in the equator, which point is called the first point of Aries, the origin of all right ascensions. The first point of Aries can always be determined by computation.

Now, the *declination* of a star will be north or south according as the meridional arc, whereby it is measured, extends towards the North or the South Pole. When a star's declination is known, its north polar distance may be computed in this way: When the declination is south add it to 90°: When it is north, subtract it from 90°: the sum or difference so obtained will be the north polar distance required.

The *horary* angle of a celestial object is the time it takes to come to the meridian or the time it has passed it.

The *latitude* of a place is an arc of the meridian, intercepted between the equator and the zenith.

The *longitude* of a place, or rather the difference of longitude between two places, is an arc of the equator intercepted between the meridians appertaining to those places.

A *siderial* day is the interval elapsed between the two successive transits of a star on the same meridian. It is divided in the usual manner into hours, minutes and seconds. A clock, truly adjusted to siderial time, will read $\overset{h.}{0}\ \overset{m.}{0}\ \overset{s.}{0}$ when the first point of Aries passes the meridian.

In like manner, the interval included between the sun's leaving a meridian and its returning to it, is styled a *solar* day.

Before proceeding any further, it is necessary to show why a *solar* day is greater than a *siderial* day. The diurnal motion of the heavens from east to west is only apparent, arising from the real motion of the earth in a contrary direction. Suppose, now, that the sun and a star are on a meridian together on any given day. On the following day the meridian

will again meet the star at the same place, but not the sun, which will have advanced about 59″ towards the east, which arc, therefore, will require to be described by the meridian before it can reach the sun, whence it is clear, that the interval (siderial day), included between the transits of a star, will be less than the like interval (solar day) for the sun.

The solar day, however, cannot be made use of to regulate and adjust a clock; because on account of the variable motion of the sun, it will not be of the same length throughout the year. To remedy this inconvenience, astronomers imagine a mean sun moving in the equator with the true sun's mean velocity in the direction of that plane, and they call the interval included between its two successive transits on the same meridian, a mean solar day. This mode of reckoning time is in general use; all astronomical clocks and chronometers, as well as common watches, being adjusted by it. The Nautical Almanac furnishes the rules for deducing the transit of the mean sun from that of the true sun.

The foregoing are all the astronomical terms which occur in this work, and they have been defined in a way in which it is hoped they will be easily apprehended by a practical man. Before the reader, however, proceeds to the perusal of the following chapters we would recommend him to acquire a knowledge of the Nautical Almanac by attentively reading over the explanation of the contents appended to that work.

It is of considerable importance to a surveyor to know the names and positions of the principal stars. The following directions from "Mackay on the Longitude" will be found of service:*

Of the fixed Stars.

The Fixed Stars are so named, because they are observed to retain their relative places with respect to each other. Some stars appear to be of a sensible magnitude to the naked eye, but when viewed through a telescope, seem only as lucid points, without any apparent diameter; hence their immense distance from the solar system is inferred, and consequently they emit their own light, otherwise they would be invisible. It is, therefore, reasonable to suppose them to be so many suns; diffusing light and heat to plants revolving round them.

The Stars, with respect to their apparent splendour, are divided into orders, called Magnitudes. The brightest are called Stars of the first Magnitude: the next to these in splendour, Stars of the second Magnitude, and so on to those which are just perceptible to the naked eye, and which are called Stars of the sixth Magnitude. Those which cannot be discerned without the assistance of a telescope, are called *Telescopic Stars*, and are divided into orders of the Seventh, Eighth, Ninth, &c. magnitudes accordingly. We are not, however, to infer from this, that the Stars can be exactly reduced to one or other of these Magnitudes,

* See also "Introduction to Practical Astronomy" by Elias Loomis, LL.D., New York, 1865. CHAPTER I.]

for the Star α Aquilæ is reckoned by some to be of the first Magnitude. others esteem it of the second; hence those stars whose Magnitudes are doubtful, are generally marked in catalogues as partaking of both Magnitudes—thus α Aquilæ is marked 1.2, signifying that it is either of the first or second, or rather between these Magnitudes; and ν Scorpionis is marked 3.4, as being between these Magnitudes; and the figure denoting the Magnitude to which the Star is nearest is put first—thus, δ Scorpionis is marked 3, 2; signifying. therefore, that it is between the second and third Magnitudes, but nearest the third. From what has been said of the Magnitudes of the Stars, we are not to suppose that their sizes are in the ratio of their apparent Magnitudes; they may perhaps be nearly of the same bulk, but the apparent Magnitude of a Star depends on its distance.

The Stars, for the purpose of finding any one more readily, are divided into parcels called CONSTELLATIONS. These, in order to assist the imagination, are supposed to be circumscribed with some known figure, as that of a *man*, *woman*, *ship*, *sextant*, &c.; and those Stars which lie between constellations are called UNFORMED STARS. As it would be an endless task to give a proper name to each Star, it has, therefore been customary to mark the Stars of each constellation with the letters of the Greek alphabet, in such a manner, that the first letter is prefixed to the brighest star, the second letter to the next in brightness, and so on. Many of the brightest of the fixed Stars have also proper names—thus, α, Bootæ, is also called *Arcturus*; β, Virginis, is called *Vindemiatrix*, &c.

The celestial sphere is divided into three parts, the ZODIAC, and the NORTHERN and SOUTHERN HEMISPHERES.

The Zodiac extends to about 8° on each side of the ecliptic, and contains the orbits of all the planets; there are 12 constellations in the Zodiac. According to the ancients, there were 21 constellations in the Northern Hemisphere, and 15 in the Southern; and consequently, 48 constellations in the zodiac and both hemispheres. Modern astronomers, however, by curtailing several of the ancient constellations of some of their stars, which they formed into new constellations; and by forming into constellations the unformed Stars, or those which lay beween the ancient ones, have increased the number of constellations in the Northern Hemisphere to upwards of 40, and those in the Southern to about 48; and consequently there are upwards of 100 constellations in all. The names of these constellations are as follows:—

ZODIACAL CONSTELLATIONS.

1 Aries,	The Ram.	7 Libra,	The Balance.
2 Taurus,	Bull.	8 Scorpio,	Scorpion.
3 Gemini,	Twins.	9 Sagittarius,	Archer.
4 Cancer,	Crab.	10 Capricornus,	Goat.
5 Leo,	Lion.	11 Aquarius,	Water Bearer.
6 Virgo,	Virgin.	12 Pisces,	Fishes.

NORTHERN CONSTELLATIONS

1 Ursa Minor,	The Little Bear.	11 Perseus,	Perseus.
2 Ursa Major,	Great Bear.	12 Auriga,	The Waggoner.
3 Draco,	Dragon.	13 Serpentarius,	Serpentarius.
4 Cepheus,	Cepheus.	14 Serpens,	The Serpent.
5 Bootes,	Bootes.	15 Sagitta,	Arrow.
6 Corona Borealis,	The Northern Crown.	16 Aquila,	Eagle.
7 Hercules,	Hercules.	17 Antinous,	Antinous.
8 Lyra,	The Harp.	18 Dolphinus,	The Delphin.
9 Cygnis,	Swan.	19 Equuleus,	Horse Head.
10 Cassiopeia,	Cassiopeia.	20 Pegasus,	Flying Horse.

NORTHERN CONSTELLATIONS.—(*Concluded.*)

21 Andromeda,	Andromeda.	32 Scutum Sobieski,	Sobieski's Shield.
22 Triang. Borealis.	The Northern Triangle.	33 Lacerta,	The Lizard.
23 Coma Berenices,	Berenice's Hair.	34 Mons Mænalus,	A Mountain of Arcadia.
24 Camelopardalus,	The Camelopard.	35 Cor Caroli,	Charles' Heart.
25 Monoceros,	Unicorn.	36 Renne,	The Rein Deer.
26 Triangulum Minus,	Little Triangle.	37 Le Messier,	M. Messier.
27 Lynx,	The Lynx.	38 Taurus Regalis,	The Royal Bull.
28 Leo Minor,	Little Lion.	39 Friedrick's Ehre,	Frederick's Glory.
29 Asterion et Chara,	Greyhounds.	40 Tubus Herschelii, Major.	Hersshel's Great Telescope.
30 Cerberus,	Cerberus.		
31 Vulpecula et Anser,	The Fox and Goose.		

SOUTHERN CONSTELLATIONS.

1 Cetus,	The Whale.	27 Pisces Volans, or Passer.	Flying Fish.
2 Orion,	Orion.	28 Dorado, ou Xiphias,	The Sword Fish.
3 Eridanus,	River Eriadanus.	29 Toucan,	American Goose.
4 Lepus,	Hare.	30 Hydrus,	Water Snake.
5 Canis Major,	Great Dog.	31 Sextans,	Sextant.
6 Canis Minor,	Little Dog.	32 Apparatus Sculptoris,	Apparatus of the Carver.
7 Argo Navis,	Ship Argo.	33 Fornax Chemica,	Chemical Furnace.
8 Hydra,	Hydra.	34 Horologium,	Clock.
9 Crater,	Cup.	35 Reticulus,	Reticulat. Rhomboid.
10 Corvus,	Crow.	36 Cælum Sculptorium,	Graving Tool.
11 Centaurus,	Centaur.	37 Equuleus Pictoris,	The Painter's Easel.
12 Lupus,	Wolf.	38 Pyxis Nautica,	Mariner's Compass.
13 Ara,	Altar.	39 Antlia Pneumatica,	Air-pump
14 Corona Australis,	Southern Crown.	40 Octans,	Octant or Hadley's Quadrant.
15 Piscis Australis,	Southern Fish.	41 Circinus,	A pair of Compasses.
16 Columba Noachi,	Noah's Dove.	42 Norma,	The Square and Rule.
17 Rober Carolinum,	Royal Oak.	43 Telescopium,	Telescope.
18 Grus,	Crane.	44 Microscopium,	Microscope.
19 Phœnix,	Phœnix.	45 Mons Mensæ,	Table Mountain.
20 Indus,	Indian.	46 Solitaire,	An Indian Bird.
21 Pavo,	Peacock.	47 Psalterium Georgianum,	The Georgian Psaltery.
22 Apus, ou *Avis Indica*,	Bird of Paradise.	48 Tubus Herschelli Minor,	Herschel's less Telescope.
23 Apis, ou *Musca*,	Bee or Fly.		
24 Crux,	Cross,		
25 Chamelion,	Chamelion.		
26 Triangulum Australis,	Southern Triangle.		

Three more southern constellations have been lately added, viz., *Montgolfier's Balloon*, which is between Sagittarius, Capricon, the Southern Fish and the Microscope; the *Press of Guttenberg*, between the Great Dog and the Ship; and the *Cat*, between Hydra, the Ship, Compass and Air-pump. The two first of these constellations were formed by astronomers at Gotha, in Upper Saxony, and the last by the late M. Jerome de la Lande.

The number of Stars of the first magnitude in the zodiac and in both hemispheres, do not amount to twenty.

The Pleiades, or as they are more commonly called the Seven Stars, although only six principal stars remain, are, it is presumed, universally known. Towards the S.E. and at the distance of nearly 14°, is the star *Aldebaran*, of the first magnitude, and of a reddish colour, which, together with a few small stars, form a triangular figure. Between the N. and E. of Aldebaran, aud about the angular distance of 45°, is *Pollux*, in the Constellation Gemini, and at a small distance to the N. is Castor. From Pollux a little to the S. of E., at the distance of about 37°, is *Regulus*, in the Constellation Leo; and from thence, at the distance of about

54° towards the east, is *Spica Virginis.* From this star, and nearly in the same direction, at the distance of about 46°, is *Antares,* of the first magnitude. From Antares to *Altair,* or *α Aquilæ,* in a north-easterly direction, the angular distance is nearly 61°. From Altair to *Fomalhaut,* in a south-easterly direction, the distance is about 59½°; and from thence to *α Pegasi,* or Markab, the distance is about 45° in a northerly direction; and from α Pegasi to *α Arietis,* the distance is about 43¾° in a direction a little to the S. of E.: and Aldebaran is distant from α Arietis about 35½°, nearly in the same direction, but inclining a little more to the south.

Some of the other principal fixed stars, which may be employed in finding the latitude and the apparent time at the place of observation, may be known by their relative bearing and distance from those already described. The following few directions may, probably, be acceptable to some persons.

An imaginary line from the Pleiades through Aldebaran, at the distance of about 16° from that star, in a south-easterly direction, will pass through Bellatrix, of the second magnitude, in the Constellation Orion; and towards the east, about 7½° from Bellatrix, is Betelguese, of the first magnitude, in the same Constellation. To the south of these stars, and nearly on a straight line, and at equal distances, are three stars, each of the second magnitude, called the Belt or Girdle of Orion: from the belt, towards the south, is the Sword of Orion, in which is a remarkable nebula; a line from Betelguese, between the first and second stars in the belt of Orion, will pass through Rigel, of the first magnitude. From Betelguese, towards the east, at the distance of about 26°, is Procyon, between the first and second magnitudes, in the Constellation Canis Minor. These two stars, and Sirius, of the first magnitude, in Canis Major, towards the south, form nearly an equilateral triangle.

From Aldebaran, in a direction a little to the E. of N., and at the distance of about 31°, is *Capella,* of the first magnitude; these two stars and Castor form nearly an isosceles triangle, Capella being at the vertex. A line from Rigel through Capella produced will nearly pass through *Alruccabah,* or the pole star; the distance between the two former being about 54°, and that between Capella and Alruccabah 44°. The pole star is the last in the tail of the Constellation Ursa Minor, which constellation contains seven principal stars, and is similar, but differently posited with respect to Ursa Major, or the Great Bear; the two westernmost stars of this Constellation, when in the hemisphere south of the pole, are called the *Pointers;* as a line through them points out, or is nearly in a direction with the pole star.

Towards the south of Regulus, and inclining a little to the west, at the distance of about 23¼°, is *Alphard,* in the Constellation Hydra. From Regulus to Deneb, the distance, in a direction to the N. of E., is about 23¾°. From Spica Virginis to Arcturus, in a northerly direction, the distance is 33°; and nearly in a line between them is *Vindemiatrix,* in Virgo; to the north of this star, at the angular distance of about 27½ degrees, is *Cor Caroli.* In a north-easterly direction from Arcturus, at the distance of 19¼ degrees, is *Alphacca,* in Corona Borealis; and from thence, nearly in the same direction at the distance of about 39¾°, is *Vega* or *α Lyra,* of the first magnitude. At the distance of 47° from Spica Virginis, towards the south, is the northernmost of four stars, forming a cross, and therefore, called the *Crosiers.*

[PART V.

Nearly 14° to the north-east of Altair, is the Constellation Delphinus, in which are four principal stars, in form of a rhomboid; and this line being produced from Delphinus, in the same direction, will pass through *Scheat*, a star of the second magnitude, in the Constellation Pegasus. About 13° to the south of Scheat, is *Markab*, a star of the second magnitude, in the same Constellation; nearly 16½° to the eastward of Markab, is *Algenib* or γ Pegasi, of the second magnitude; and about 14° to the eastward of Scheat, is α Andromedæ, or Alpheratz, a star of the third magnitude, in the head of Andromeda. These four stars form a figure, which is usually called the *Square of Pegasus*.

From α Andromedæ in a north-easterly direction, at the distance of nearly 14½°, is *Mirach*; and 23¾° thereform, in the same direction, is the variable star *Algol*. In a perpendicular direction from the middle of the line joining Mirach and Algol, towards the north, and at the distance of about one-eighth of that line, is *Almaach*. About 21½°, towards the north of Mirach is *Schedir* in Cassiopeia; this Constellation contains five stars of the third magnitude, and is easily known. Between the south and west of the Pleiades, at the distance of 23°, or from Aldebaran 26°, is *Menkar*, of the second magnitude. Betelguese, Rigel, and *Achernar* are nearly in the same direction, the distance between the two last being 4½ times of that between the two first.

CHAPTER II.

On the determination of the error of a Chronometer; and of the Azimuth of the Referring Mark from observations made at any time on the Sun or a known Star.

When a chronometer forms a part of the equipment of a surveyor, the first thing he must apply himself to, is the determination of its error. This may be easily effected by an observation taken at any time to the sun or a star in the following manner: First, to begin with the sun, which, suppose, is on the east of the meridian. With a theodolite properly adjusted, take the altitude of the sun's upper limb, noting the chronometer time of the observation. Then as the sun is ascending, allow the telescope to stand at the same elevation, and mark the chronometer time when the lower limb attains to that altitude. This will complete observations on one face of the instrument, and similar observations being repeated on the other face, there will be two observed altitudes and four chronometer times, the mean of the former is obviously the altitude of the sun's centre, divested of instrumental errors; the chronometer time corresponding thereto being the mean of the four observed times aforesaid.

On the other hand, when the sun is on the west of the meridian, and descending, the lower limb will require to be observed first and then the upper; a contrary procedure being followed on the eastern side, because the sun was ascending. With the exception of this difference, the observations on both sides of the meridian are to be conducted in exactly the same manner.

The altitude of the sun's centre being derived in the way described above, the next step is to clear it of refraction and parallax (*vide* Appendix, Tables E and F), an operation which will furnish what is technically called the true altitude. Deduct this altitude from 90°, the remainder will be the zenith distance of the sun's centre.

Besides the zenith distance, there will be two other quantities required in the present computation, and these are: 1st, the sun's north polar distance; and 2nd, the co-latitude of the place of observation: the former may be taken out from the Nautical Almanac, while the latter

must be derived from observations made for that purpose, or from a previous survey operation.

The three elements, viz. the sun's zenith and north polar distances, and the co-latitude of the place, being obtained, the computation of the chronometer error may be performed in the following manner:

1st.—Collect into one sum the zenith and the north polar distances of the sun, and the co-latitude of the place, and take its half: then diminish the half sum by 1st the zenith distance, 2nd the north polar distance, and 3rd the co-latitude, and call these differences in the order in which they are taken, D_1, D_2, D_3.

2nd.—To the log cosecant of the half sum as taken above add the log cosecant of D_1, and the log sines of D_2 and D_3; the sum divided by 2 is the log tangent of an arc, which being found and doubled, will furnish the sun's horary angle at the time of observation.

3rd.—The horary angle being in space must now be converted into time, and then subtracted from the mean time of the apparent noon or added thereto, according as the observation was made on the east or west of the meridian. See Tables following. The difference or the sum (as the case may be) so obtained, will be the mean time of the observation.

This mean time may now be compared with the mean observed time, and the difference between the two will be the error of the chronometer.

TABLE I.

For converting Degrees, Minutes and Seconds into Time, at the rate of 360 Degrees for 24 Hours.

Deg Min.	Hou. Min. Min. Sec.	Deg. Min.	Hou. Min. Min. Sec.	Sec.	Dec. of Sec.
1	0—4	30	2—0	1	·067
2	0—8	40	2—40	2	·133
3	0—12	50	3—20	3	·2
4	0—16	60	4—0	4	·266
5	0—20	70	4—40	5	·333
6	0—24	80	5—20	6	·4
7	0—28	90	6—0	7	·466
8	0—32	100	6—40	8	·533
9	0—36	200	13—20	9	·6
10	0—40	300	20—0	10	·666
20	1—20				

TABLE II.

For converting Time into Degrees, Minutes and Seconds, at the rate of 24 Hours for 360 Degrees.

Hou. Deg.	Deg.	Min. Sec.	Deg. Min. Min. Sec.	Dec. of Sec.	Sec.
1	15	1	0—15	·1	1·5
2	30	2	0—30	·2	3·0
3	45	3	0—45	·3	4·5
4	60	4	1—0	·4	6·0
5	75	5	1—15	·5	7·5
6	90	6	1—30	·6	9·0
7	105	7	1—45	·7	10·5
8	120	8	2—0	·8	12·0
9	135	9	2—15	·9	13·5
10	150	10	2—30		
11	165	20	5—0		
12	180	30	7—30		
16	240	40	10—0		
20	300	50	12—30		

EXAMPLE.

SPECIMEN OF THE FIELD BOOK.

Afternoon Observations taken on the Sun at the Surveyor-General's Office, Dehra, 15th August, 1848.

Object observed.	Face.	Vertical Vernier. A. °	′	″	B. °	′	″	Mean. °	′	″	Observed Chronometer Times. h.	m.	s.
☉'s Lower Limb ...	L	19	45	45	19	45	15	19	45	30	10	51	29
„ Upper Limb ...	„	19	45	45	19	45	15	19	45	30	10	53	59
„ Lower Limb ...	R.	18	54	45	18	54	15	18	54	30	10	56	20
„ Upper Limb ...	„	18	54	45	18	54	15	18	54	30	10	58	49

Mean observed altitude = 19° 20′ 0″

do. time = 10h. 55m. 9s.

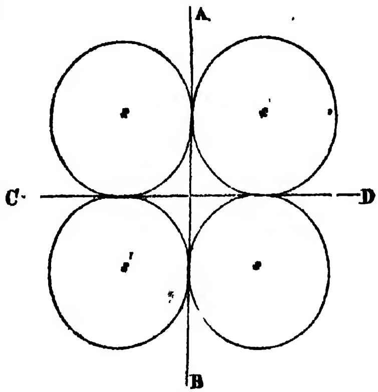
Type of Computation.

	°	′	″		
Mean observed Altitude	19	20	0		
Refraction and Parallax	—	2	36		
True Altitude	19	17	24		
Zenith Distance	70	42	36		
North Polar Distance	76	2	46		
Co-latitude	59	40	8		
Sum	206	25	30		
Half Sum	103	12	45	Cosec.	0·0116511
Half Sum diminished by zenith distance D_1 ...	82	30	9	Cosec.	0·2697537
Ditto ditto North Polar Distance D_2 ...	27	9	59	Sin.	9·6595132
Ditto ditto Co-latitude D_3 ...	43	32	37	Sin.	9·8381608
					2)19·7790788
Half the Horary Angle	37	47	27	Tan.	9·8895392
			2		
Horary Angle in Space	75	34	54		

	h.	m.	s.
Horary Angle in Time	5	2	19
Mean Time of Apparent Noon.	0	4	13
Mean Time of observation .	5	6	32
Chronometer Time of ditto .	10	55	9
Chronometer Error	5	48	37

On account of the difficulty of intersecting the sun's centre, four observations, as has been seen, are necessary to determine its altitude. Such a rigorous procedure, however, is not required for a star which is a small object, and easily intersected. With a properly-adjusted theodolite, take two altitudes to a star on each face, noting the chronometer time of each observation. The mean observed altitude, as likewise the mean observed chronometer time being computed, and the former cleared of refraction, the deduction of the horary angle may be taken in hand, for which the process to be followed is the same as that for the sun. The horary angle being deduced, it must now be added to or subtracted from the star's apparent right ascension, according as the observation was made on the west or east of the meridian. The resulting sum or difference will be the sidereal time of the observation, which reduced to mean solar time, and compared with the mean observed time, will furnish the error of the chronometer.

Analogous to this process of ascertaining the error of a chronometer, there exists a method for determining the azimuth of a survey. To accomplish the latter object, the surveyor will establish a referring mark at the distance of a mile from the station of observation, so that it may be visible with the solar focus of the telescope attached to his theodolite. When the referring mark has been selected with due regard to this condition, he will proceed with his observations upon the sun in the following manner.



Adjust the theodolite over the station dot, and take a reading to the referring mark, after which, turn the telescope to the sun, and placing it in one of the four angles of the wires, make those wires tangents to its sides, as shewn in the annexed figure, in which AB and CD represent

the wires and S,S, S', S' the sun. Now read off the horizontal and vertical limbs of the instrument. This done, take a similar observation of the sun in the opposite angle of the wires,* after which, bring the telescope to the referring mark, and take a second intersection thereof.

Now, compute the difference between the first azimuthal reading of the referring mark and the like reading of the sun, this will be one angle. Again, performing a similar operation upon the second pair of readings, there will result another angle. The mean of these two angles will obviously be the angle between the sun's centre and the referring mark on one face. In like manner, the mean of the vertical angles observed will be the altitude of the sun's centre on the same face.

Similar observations being made on the reversed face of the instrument, there will ultimately arise a horizontal angle and an altitude, analogous to the horizontal angle and altitude mentioned above. The mean, therefore, between the two horizontal angles so deduced will be the angle between the referring mark and the sun's centre, cleared of facial error. For the same reason, the mean between the two altitudes will be the elevation of the sun's centre, divested of all instrumental discrepancies.

The foregoing data being obtained, the next step is the computation of the sun's azimuth. The elements involved in this deduction are 1st—the sun's true zenith distance; 2nd—its north polar distance; and 3rd—the co-latitude of the place: the mode of deriving which having been explained in a former part of this chapter, it will not be necessary to enter into that subject again at this place.

Combine into one sum the sun's north polar and zenith distances and the co-latitude of the place, and take its half. Diminish this half sum by 1st the north polar distance, 2nd the zenith distance, and 3rd the co-latitude, and call these differences taken in succession D', D'' and D'''.

To the log cosecant of half sum add the log cosecant of D' and log sines of D'' and D'''. The resulting sum divided by 2 will be the log tangent of an arc, which being found and doubled, will be the sun's azimuth at the time of observation.

The sun's azimuth as deduced above originates from the north, and extends towards the east or west as the observation was made on one or the other side of the meridian. Apply now this azimuth to the mean observed angle between the sun's centre and the referring mark, the resulting arc will be the required azimuth of the latter.

* In the Diagram the $\angle S$ is opposite to the $\angle S$ and the $\angle S'$ to S'.

EXAMPLE.

SPECIMEN OF THE FIELD BOOK.

Morning Angles taken at Allahabad, Surveyor-General's Office, 21st May, 1845.

Objects observed.	Face.	Vernier Readings. A.	Vernier Readings. B.	Vernier Readings. C.	Vernier Readings. Mean.	Angles deduced. One Reading.	Angles deduced. Mean at each Zero.	No. of Observations at each Zero.	Vertical Verniers. A.	Vertical Verniers. B.	Vertical Verniers. Mean.
		° ′ ″	′ ″	′ ″	° ′ ″	° ′ ″	° ′ ″		Altitudes. ° ′	′ ″	° ′ ″
Referring Mark ...	R	275 26 45	27 15	26 15	275 26 45						
☉'s (Left and Lower Limb)		224 48 15	48 45	48 15	224 48 25	50 38 20	50 40 10	2	14 27 45	25 15	14 26 30
☉'s (Right and Upper) ...		224 44 45	45 0	45 0	224 44 55	50 42 0			15 3 45	2 15	15 3 0
Referring Mark ...		275 26 45	26 45	27 15	275 26 55					Mean...	14 44 45
Referring Mark ...	L	95 26 45	27 15	26 30	95 26 50						
☉'s (Left and Lower) ...		46 27 15	27 45	27 15	46 27 25	48 59 25	49 3 10	2	18 26 15	25 15	18 25 45
☉'s (Right and Upper) ...		46 19 15	19 45	19 45	46 19 35	49 6 55			18 56 15	55 15	18 55 45
Referring Mark ...		95 26 45	26 15	26 30	95 26 30					Mean...	18 40 45

	° ′ ″		
Mean observed Altitude	16 42 45		
Refraction and Parallax	— 3 3		
True Altitude ...	16 39 42	Mean observed angle between the Sun and Referring Mark ...	49 51 40
Zenith Distance ...	73 20 18		

Type of Computation.

	°	′	″		
☉'s North Polar Distance	69	40	34		
„ Zenith Distance	73	20	18		
Co-latitude of the place	64	35	30		
Sum	207	36	22		
Half Sum	103	48	11	Cosec.	0·0127264
Half Sum diminished by North Polar Distance, D′ ...	34	7	37	Cosec.	0·2510152
Ditto ditto Zenith Distance D″ ...	30	27	53	Sin.	9·7050146
Ditto ditto Co-latitude D‴ ...	39	12	41	Sin.	9·8008430
					2)19·7695992
	87	29	19	Tan.	9·8847996
			2		
☉'s Azimuth	74	58	38		
Observed Angle between ☉ and referring mark	49	51	40		
Azimuth of the referring mark	124	50	18		

To make the foregoing process of observation and computation applicable to a star, take, as in the case of the sun, its altitude, and the angle which it may be inclined to with the referring mark. These observations will require to be repeated on both faces of the theodolite, and the mean results taken to free the latter from instrumental errors. This done, clear the mean observed altitude of refraction, and deduce therefrom the star's true zenith distance. With this element, and the star's apparent north polar distance, and the given co-latitude of the place, compute the star's azimuth in the same way as in the case of the sun, which azimuth, applied to the mean observed angle between the star and the referring mark, will furnish the azimuth of the latter.

To give the surveyor an idea of the accuracy attainable by this method of determining the azimuth, the results of thirteen observations taken in the Revenue Survey of the 24-Pergunnahs are here given, the mean whereof, when compared with the corresponding azimuth in the Trigonometrical Survey, exhibits an error of 27″.

Results of Observations taken at No. 46 (new) Park Street, with a Troughton and Simms's 7-inch Theodolite of Colonel Everest's or East India Company's Pattern.

Date.	Stars observed.	Deduced Azimuth of La Martiniere Dome.
17th Oct., 1848	α Cassiopeia	168° 11′ 44″
19th " "	α Scorpio (Antares) ...	11 12
23rd " "	α Bootes (Arcturus) ...	12 32
25th " "	Ditto ...	10 8
28th " "	α Scorpio (Antares) ...	10 50
2nd Nov., "	η Ursæ Major	10 22
3rd " "	α Cassiopeia	11 28
3rd " "	α Scorpio (Antares) ...	11 44
3rd " "	α Tauri (Aldebaran) ...	11 39
6th " "	α Auriga (Capella) ...	11 56
8th " "	α Tauri (Aldebaran) ...	11 8
8th " "	α Lyræ (Vega) ...	11 56
8th Mar., 1849	Sun	11 32

	°	′	″
Mean	168	11	24
By Great Trigonometrical Survey	168	11	51
Discrepancy			27

These azimuths originate from the north; that of the Great Trigonometrical Survey is derived in the following manner:

	°	′	″
Azimuth of 46 (new) Park Street, from La Martiniere, measured from south, furnished by the Officer in charge of the Coast Series ...	168	11	53·3
The same augmented by π or 180°	348	11	53·3
Correction for the convergency of the meridian		—	2·6
Azimuth of La Martiniere from 46 (new) Park Street, reckoned from south	348	11	50·7
The same reckoned from north	168	11	50·7

CHAPTER III.

ON THE DETERMINATION OF THE ERROR AND RATE OF A CHRONOMETER, UPON MEAN SOLAR AND SIDEREAL TIME, FROM MERIDIONAL OBSERVATIONS.

WHEN the direction of the meridian, or which is the same thing, the azimuth of the referring mark, is known, the most convenient method of determining the error of a chronometer upon mean solar time is by taking a meridional observation of the sun. With this view, about half an hour before noon, plant the theodolite over the station dot, and perform thereon all the necessary adjustments. This done, take a reading to the referring mark, and apply thereto the azimuth of that point; the resulting reading will obviously be the direction of the meridian. The instrument being now set to this reading and clampt, fix the telescope to the required altitude of the sun, and await its coming. When the sun has entered the telescope, bring it into the middle of the field by the motion of the vertical tangent screw alone, and then, as it advances forward, note the chronometer times of the contact of the first and second limbs with the vertical wire of the telescope. Half the sum of the two observed times will furnish the transit of the sun's centre over the vertical wire, or the meridian of the station of observation.*

When the sun's centre passes over a meridian, it is *apparent noon* there. The mean time of the apparent noon for a given day at any place being deducible from the Nautical Almanac, it is clear, that this time compared with the observed time of the transit of the sun's centre as deduced above, will obviously furnish the error of the chronometer.

Again, the difference of the errors of the chronometer on two successive days will be its rate.

* In case both the limbs have not been observed, the method whereby the transit of the sun's centre may be derived from the transit of *one* of the limbs is as follows:—In the Nautical Almanac is registered the sidereal time of the sun's semidiameter passing the meridian for every day in the year. Take this time and add it to, or subtract it from, the observed chronometer time, according as the 1st or the 2nd limb was taken, the resulting sum or difference will be the required chronometer time of the transit of the sun's centre.

EXAMPLE.

Computation of the Observations made on the Sun at Kaliana, G. T. Station, in Lat. 29° 30′ 49″ and Long. 77° 41′ 52″.

October 1836.	Transits of the two Limbs.	Transit of the Centre.	Mean Time of apparent noon.	Error.	Rate.
	h. m. s.	h. m. s.	h. m. s.	Fast. h. m. s.	Gaining. s.
5th	{ 0 2 53·9 0 5 2·0 }	0 3 57·95	23 48 26·04	0 15 31·91	
6th	{ 0 3 8·0 0 5 17·0 }	0 4 12·50	23 48 8·57	0 16 3·93	32·02
7th	{ 0 3 22·0 0 5 31·0 }	0 4 26·50	23 47 51·50	0 16 35·00	31·07
8th	{ 0 3 38·5 0 5 47·5 }	0 4 43·00	23 47 31·86	0 17 8·14	33·14

Circumstances, however, will sometimes happen, which will prevent the sun being observed. In this case, it will be necessary to resort to the transit of a star, which may be taken in the following manner:—The theodolite being duly adjusted in the plane of the meridian, the telescope may be fixed to the altitude of the star. When the star appears in the field of the telescope, it must be brought to the middle thereof, as in the case of the sun, by the motion of the vertical tangent screw only. This done, note the chronometer time of the star's passage over the vertical wire, which will be the observed time of the transit.

It is always convenient to select a Nautical Almanac star for such observations, because its apparent right ascension being given, the computation of its transit will present little or no difficulty. For this reason we will suppose that a Nautical Almanac star has been taken. Now, the sidereal time of its transit is known, it being the star's apparent right ascension at that instant, an element which is furnished by the Nautical Almanac. Again, the same work gives the sidereal time of the mean noon for every day in the year. For any given day therefore take the sidereal time of the mean noon corrected for the longitude of the place of observation, and deduct it from the star's apparent right ascension, the difference will be the sidereal interval between the mean noon and the star's transit; which interval converted to mean solar time, will be the mean time of the transit in question.*

* The method of converting a sidereal interval into a mean solar interval and *vice versâ* is explained in the Nautical Almanac.

The mean time of the star's transit being computed, it may be compared with the observed time, and the error and rate of the chronometer determined in the same way as in the case of an observation on the sun.

EXAMPLE.

Computation of Transit Observations made on 15 *Argus at Noh, G. T. Station, in Lat.* 27° 50′ 44″ *and Long.* 77° 41′ 13″.

April 1837.	*'s Apparent Right Ascension.	Sidereal Time of Mean Noon.	Mean Time of *'s Transit.	Chronometer Time of Transit.	Error.	Rate.
					Fast.	Gaining.
	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	s.
5th	8 0 36·66	0 53 27·66	7 5 59·02	9 32 51·73	2 26 52·71	
6th	8 0 36·64	0 57 24·21	7 2 8·10	9 29 44·98	2 27 41·88	49·17
7th	8 0 36·63	1 1 20·76	6 58 7·18	9 26 37·80	2 28 30·62	48·74

Such is the way in which the error and rate of a chronometer are computed upon the mean solar time. If the error and rate are required upon the sidereal time, however, the procedure to be followed is exactly similar to that just described. For instance, suppose a transit of the sun or that of a star has been taken, the apparent right ascension of the object observed, compared with the time of observation, will furnish the error of the chronometer upon sidereal time. Again the comparison of two errors determined in this way on two or more consecutive days, will give the required rate.

As an example of this computation, take the same observations made on the sun at Kaliana, in October 1836.

Deduction of the Sidereal Error and Rate of a Chronometer.
Kaliana Station of Observation.

October 1836.	Transit of ☉'s centre.	Apparent Right Ascension.	Error.	Rate.
			Slow.	Losing.
	h. m. s.	h. m. s.	h. m. s.	m. s.
5th ...	0 3 57·95	12 44 18·61	12 40 20·66	
6th ...	0 4 12·50	12 47 57·64	12 43 45·14	3 24·48
7th ...	0 4 26·50	12 51 37·09	12 47 10·59	3 25·45
8th ...	0 4 43·00	12 55 16·95	12 50 33·95	3 23·36

In the preceding computation, it is assumed that the true azimuth of the referring mark is given, and that the theodolite has been exactly placed in the plane of the meridian. It is evident that these are conditions which cannot be readily fulfilled in practice. For instance, it may happen, that only an approximate azimuth of the referring mark is forthcoming; or that if the true azimuth is known, the theodolite has not been truly adjusted thereto. In either case, therefore, there will be an error in the setting of the instrument, and when that error is known, the observed time of the sun's or the star's transit will require to be reduced to the meridian, which may be done in the following manner:

To the logarithm of the azimuthal deviation of the theodolite from the meridian taken in seconds, add the log. sine of the zenith distance of the object observed, the log. secant of its declination, and the arithmetical complement of the logarithm of 15, the natural number answering to the sum will be the required correction in seconds of time, positive if the transit observation were made to the east, and negative if it were taken to the west of the meridian.

When this correction is applied to the observed time of the transit, the resulting element will be the true chronometer time of the meridional passage of the sun or the star observed.

EXAMPLE.

At G. T. Station Noh, the theodolite was placed 3″·835 to the west of the meridian on the 6th April 1837, and the transit of 15 Argus observed. The correction to the transit time for this azimuthal deviation may be computed as follows:—

Azimuthal deviation ...	...	... 3″·835	Log.	0·58377
Zenith Distance of 15 Argus	...	51° 41′ 10″	Sin.	$\bar{1}$·89466
South Declination of the same	...	23 50 26	Sec.	0·03873
A. C. of Log. 15	...	...	...	$\bar{2}$·82391
Correction in seconds of time	...	... —0ˢ·22	Log.	$\bar{1}$·34107

Now, the observed time of the transit was 9h. 29m. 45·20s, which being diminished by this correction will furnish 9h. 29m. 44·98s, as the chronometer time of the star's passage over the meridian. Accordingly this corrected time has been made use of in computing the chronometer errors at page 578.

CHAPTER IV.

On the Determination of the Error of a Chronometer from Observations on a high and low Star.

There is a method of ascertaining the error and rate of a chronometer, which only requires an approximate knowledge of the azimuth of the referring mark. The method consists in taking the transits of a high and low star* with a theodolite placed as nearly as possible in the plane of the meridian. The only precaution to be attended to in taking these observations is, that when the instrument is once set to the meridian, it must not be moved in azimuth, until both the required transits are taken.

The transits of a high and low star, taken as directed above, furnish two results at once: namely, 1st, the deviation of the instrument from the plane of the meridian; and 2nd, the error and rate of the chronometer. The former of these articles having been treated of in sufficient detail in a former part of the work (pages 109 to 111), it need not again occupy our attention at this place; the latter, however, is the especial subject of this chapter, and to that accordingly we will direct the attention of the reader.

The problem of determining times from the transits of a high and low star, may be divided into two cases: 1st, when the high star is observed above the pole; and 2nd, when it is taken below the pole. Each of these cases may again be subdivided into two others, with reference to the north or south position of the low star with respect to the equator.

The separate consideration of the several cases is necessary to the due understanding of the formulæ, which will be given presently.

We will suppose that the stars selected for observation are those of the Nautical Almanac, and use the following symbols to designate the computed and observed elements appertaining to them.

* "In general, the two stars suitable for this purpose ought to have opposite declinations, one north and the other south, having nearly the same right ascension, and being removed from each other by not less than forty degrees."—*Pearson's Astronomy, Vol. 2nd, p. 331.*

Explanation of the Symbols.

	High Star.	Low Star.
Apparent Declination as given in the Nautical Almanac for the date nearest the time of observation ...	d	d'
Apparent Right Ascension at the time of Transit ...	Æ	Æ$'$
Observed time of Transit ...	t	t'
Correction for time of Transit	δp	$\delta p'$

λ = Latitude of the place of observation.

To compute t^s.

Take the difference between the right ascensions of the two stars, and convert it to chronometer time; compute likewise the difference between the observed times of their transits; subtract one difference from the other, and call the resulting quantity t^s, which will require to be taken in seconds and in decimals thereof.

The fundamental quantity t^s being computed, the corrections δp and $\delta p'$ may be deduced by the following formulæ :—

Case I.—When the high star is observed above the pole, the low star having north declination.

$$\delta p = \frac{\cos d' \sin (d-\lambda)}{\cos \lambda \sin (d-d')} . t^s$$

$$\delta p' = \frac{\cos d \sin (\lambda-d')}{\cos \lambda \sin (d-d')} . t^s$$

The low star having south declination.

$$\delta p = \frac{\cos d' \sin (d-\lambda)}{\cos \lambda \sin (d+d')} . t^s$$

$$\delta p' = \frac{\cos d \sin (\lambda+d')}{\cos \lambda \sin (d+d')} . t^s$$

Table exhibiting the signs of corrections δp & $\delta p'$

Conditions.	Signs of Correction. δp.	$\delta p'$.
When the low star transits after the high star, or	$t' > t$.	
$t'-t >$ Æ$'-$Æ...	+	—
$t'-t <$ Æ$'-$Æ...	—	+
When the high star transits after the low star, or	$t > t'$.	
$t-t' >$ Æ$-$Æ$'$	—	+
$t-t' <$ Æ$-$Æ$'$...	+	—

Case II.—When the high star is observed below the pole, the low star having north declination.

$$\delta p=\frac{\cos d' \sin (\lambda+d)}{\cos \lambda \sin (d+d')} \cdot t^s$$

$$\delta p'=\frac{\cos d \sin (\lambda-d')}{\cos \lambda \sin (d+d')} \cdot t^s$$

The low star having south declination.

$$\delta p=\frac{\cos d' \sin (\lambda+d)}{\cos \lambda \sin (d-d')} \cdot t^s$$

$$\delta p=\frac{\cos d \sin (\lambda+d')}{\cos \lambda \sin (d-d')} \cdot t^s$$

Table exhibiting the signs of corrections δp & $\delta p'$.

Conditions.	Signs of Correction.	
	δp.	$\delta p'$.
When the low star transits after the high star, or	$t' > t$.	
$t'-t > \text{Æ}'-\text{Æ}$...	+	+
$t'-t < \text{Æ}'-\text{Æ}$	—	—
When the high star transits after the low star, or	$t > t'$.	
$t-t' > \text{Æ}-\text{Æ}'$	—	—
$t-t' < \text{Æ}-\text{Æ}'$...	+	+

Of the four heads under which the formulæ of computation are given, the intelligent surveyor will take that which will suit his case, and proceed with his arithmetical deductions accordingly.

When δp and $\delta p'$ are computed, and proper signs affixed thereto, they may be applied, the former to t, and the latter to t'; the resulting elements will be the times of the meridional passages of the stars observed; whereby the error and the rate of the chronometer may be easily determined.

EXAMPLE.

Computation of the Transit Observations made at Sora, Karara Series Station, in October, 1845.

**Latitude of Sora* = 26° 17′ 17″, *Longitude* 81° 14′ 50″ *or* 5·416*h.*

Date.	Apparent Right Ascensions.		Ʀ—Ʀ′	Ʀ — Ʀ′ in Chronometer Time.	Observed Times of Transits.		$(t-t'.)$	t^s.	$\delta p'$.	δp.
	α^2Capricorni.	λ Ursæ Minoris.			α^2Capricorni.	λ Ursæ Minoris.				
	h. m. s.	h. m. s.	s.	s.	h. m. s.	h. m. s.	s.	s.	s.	s.
9	20 9 30·65	20 16 59·01	448·36	447·34	1 56 14·5	2 2 39·0	384·5	62·84	—0·91	+61·93
10	20 9 30·63	20 16 57·86	447·23	446·21	1 52 58·0	2 59 24·5	386·5	59·71	—0·86	+58·86
11	20 9 30·61	20 16 56·71	446·10	445·08	1 49 39·2	1 56 6·0	386·8	58 28	—0·84	+57·45
12	20 9 30·60	20 16 55·55	444·95	443·94	1 46 21·2	1 53 13·0	411·8	32·14	—0·46	+31·68
13	20 9 30·58	20 16 54·38	443·80	442·79	1 43 6·3	1 49 43·0	396·7	46·09	—0·66	+45·43

Table exhibiting the Results of the Transit Observations taken at Sora, Karara Series Station, in October, 1845.

a^2 Capricorni.

Date.	Chronometer Times of Transit.	$\delta p'$	Chronometer Times Corrected.	Apparent Right Ascensions.	Choronomter.	
					Error.	Rate.
	h. m. s.	s.	h. m. s.	h. m. s.	h. m. s.	m. s.
9	1 56 14·5	— 0·91	1 56 13·59	20 9 30·65	18 13 17·06	
10	1 52 58·0	— 0·86	1 52 57·14	20 9 30·63	18 16 33·49	3 16·43
11	1 49 39·2	— 0·84	1 49 38·36	20 9 30·61	18 19 52·25	3 18·76
12	1 46 21·2	— 0·46	1 46 20·74	20 9 30·60	18 23 9·86	3 17·61
13	1 43 6·3	— 0·66	1 43 5·64	20 9 30·58	18 26 24·94	3 15·08

λ *Ursæ Minoris*

Date.	Chronometer Times of Transit.	δp	Chronometer Times Corrected.	Apparent Right Ascensions.	Chronometer.	
					Error.	Rate.
	h. m. s.	s.	h. m. s.	h. m. s.	h. m. s.	m. s.
9	2 2 39·0	+ 61·93	2 3 40·93	20 16 59·01	18 13 18·08	
10	1 59 24·5	+ 58·86	2 0 23·36	20 16 57·86	18 16 34·50	3 16·42
11	1 56 6·0	+ 57·45	1 57 3·45	20 16 56·71	18 19 53·26	3 18·76
12	1 53 13·0	+ 31·68	1 53 44·68	20 16 55·55	18 23 10·87	3 17·61
13	1 49 43 0	+ 45·43	1 50 28·43	20 16 54·38	18 26 25·95	3 15·08

It is necessary to remark that the chronometer errors and rates, deduced in this example, are upon sidereal time, and if they are required in terms of the mean time, the necessary reduction may be easily made by a reference to the following Chapter.

CHAPTER V.

On the Conversion of a given Chronometer Time to the corresponding Mean Solar and Sidereal Time, and vice versa.

It will have already appeared to the reader of the foregoing pages, that whether the error of a chronometer is determined from a meridional or an extra-meridional observation, the general principle of deduction is the same in both cases. For instance, in either case, the *mean solar time* of the observation is first computed. It is then compared with the *observed time*, and the difference between the two is taken as the error of the chronometer.

It is convenient to have this process expressed in algebraical symbols. For this purpose, let s designate the *mean solar time* of an observation, and c the *chronometer time* corresponding thereto, then $s \backsim c = e$ is the chronometer error at the instant of that observation. Again, calling s' and c' analogous elements to s and c for a subsequent observation, there will arise $s' \backsim c' = e'$ the chronometer error at the time of the second observation.

Suppose t to be the chronometer time lying between c and c', which is required to be converted to mean solar time. It is clear that if the chronometer error ϵ at the time t, were known, then $t \pm \epsilon$ would be the *mean solar time* sought, the upper sign being used when $s > c$, and the lower sign when $s < c$.

The term ϵ may be computed in the following manner: subtract c from c' and t, the resulting terms $(c'—c)$ and $(t—c)$ will represent chronometer intervals, the former between c' and c, and the latter between t and c. Again $e' \backsim e$ stands for the rate, or the increment or decrement (as the case may be) of the chronometer error engendered during the interval $(c'—c)$. Now assuming rates to be proportional to the intervals, during which they are produced, we shall have

$$(c—c') : (e' \backsim e) :: (t—c) : ——$$

The fourth term, when brought out, will represent the rate produced during the interval $(t—c)$. When the first error e has been corrected by this rate, the resulting term will obviously be ϵ or the error at the time t.

EXAMPLE.

Suppose at Kaliana, 5th October, 1836, the given chronometer time is $5^h\ 58^m\ 27^s$, it is required to compute the mean solar time corresponding thereto.

On reference to page 578, it will be seen that the numerical values of s, c, e .. for the 5th and 6th of October, are as follows:

5th October

	h.	m.	s.
$s =$	23	48	26·04
$c =$	0	3	57·95
$e =$	0	15	31·91
$c' - c =$	24	0	14·55
$t - c =$	5	54	29·05
$\acute{e} \backsim e =$			32·02

6th October.

	h.	m.	s.
$s' =$	23	48	8·57
$c' =$	0	4	12·50
$\acute{e} =$	0	16	3·93

Rate for $(t-c)$ Computed.

$(c'-c)$	in seconds	86114·55	Log. 4·9365869
			A.C. $\bar{5}$·0634131
$\acute{e} \backsim e$	ditto	32″·02	Log. 1·5054213
$(t-c)$	ditto	21269·05	Log. 4·3277481
Required rate	...	7″·88	Log. 0·8965825

This rate is positive, because the error is increasing, e being $< \acute{e}$

Hence $\epsilon = 0^h\ 15^m\ 31^s{\cdot}91 + 7^s{\cdot}88 = 0^h\ 15^m\ 39^s{\cdot}79$

and $(t-\epsilon) = 5\ 42\ 47{\cdot}21$ mean solar time corresponding to t.

After having reduced a given chronometer time to the corresponding mean solar time, the latter may now be converted to sidereal time, in the following manner:

Refer to the Nautical Almanac and take out the mean time of the transit of the first point of Aries immediately prior to the given mean time. Now deduct this transit time from the given mean time, the difference converted to sidereal interval will be the sidereal time sought.

EXAMPLE.

Take the mean solar time given above for Kaliana, 5th October, 1836.

	h.	m.	s.
Given mean solar time	5	42	47·21
Mean time of transit of first point of Aries	11	6	12·65
Mean solar interval...	18	36	34·56
Corresponding sidereal interval or the sidereal time sought.........	18	39	37·99

The transit of the first point of Aries used in this computation belongs to the 4th October, because it is that which immediately precedes the *mean time*, the same point transiting on the 5th, which is after the *given time*.

In the foregoing part of this chapter, the chronometer errors e and $\acute{e}$ are taken with reference to the *mean solar time.* This however is a circumstance which cannot always be expected to obtain in practice. For instance, it may sometimes happen that the terms e and e' are known with reference to the *sidereal time* only. When this is the case, the given chronometer time t cannot at once be reduced to the corresponding *mean solar time.* It must, in the first place, be converted to *sidereal,* and then if required, to *mean solar time.*

With respect to the former of these reductions, the process to be followed is exactly similar to that used for the conversion of any given chronomter to the corresponding *mean solar time,* the given terms s, e, s', e' in this instance being taken in terms of the sidereal, in lieu of the mean solar time. When the sidereal time is computed, the corresponding mean solar time may be determined in the following manner:

Take out from the Nautical Almanac the sidereal time of the mean noon, immediately preceding the given sidereal time. Subtract the mean noon time so found from the given sidereal time, the difference converted to mean solar interval will be the mean time sought.

EXAMPLE.

In illustration of this computation take the same example as that given before, *viz.,* the chronometer time $t = 5^h\ 58^m\ 27^s$ as observed at Kaliana, 5th October, 1836, and it is required to reduce it successively to the corresponding sidereal and mean solar times.

The sidereal values of s, e, s', and $\acute{e}$, as given at page 578, are as follows:

5th October, 1836.	h. m. s.	*6th October.*	h. m. s.	
$s =$	12 44 18·61	$s' =$	12 47 57·64	
$c =$	0 3 57·95	$c' =$	0 4 12·50	
$e =$	12 40 20·66	$\acute{e} =$	12 43 45·14	sidereal errors.

	h. m. s.	
$c'-c =$	24 0 14·55	
$t-c =$	5 54 29·05	
$\acute{e}-e =$	3 24·48	sidereal rate.

Sidereal rate for (t—c) Computed.

$c'-c$ in seconds		86414·55	Log.	4·9365869
			A. C.	$\bar{5}$·0634131
$\acute{e}-e$	ditto	204·48	Log.	2·3106508
$t-c$	ditto	21269·05	Log.	4·3277481
Required sidereal rate		50·33	Log.	1·7018120

Hence $\epsilon = 12^h\ 40^m\ 20^s{\cdot}66 + 50^s{\cdot}33 = 12^h\ 41^m\ 10^s{\cdot}99$

And $(t + \epsilon) = 18\ 39\ 37{\cdot}99$ siderial time corresponding to t.

In this case, ϵ is made + because $s > c$.

To compute the Mean Solar Time answering to Chronometer Time t.

	h. m. s.
Computed sidereal time for t	18 39 37·99
Sidereal time of mean noon for 5th October..	12 55 54·46
Difference	5 43 43·53
Difference reduced to mean solar interval or the mean time required......	5 42 47·21

Before this chapter is concluded, it is necessary to show the method of working the following problem :

Given a mean solar or a sidereal time δ, to compute the chronometer time t corresponding thereto. Retaining the characters we have already used, we will represent by s and s' the mean solar or the sidereal times (as the case may be) of the two *time* observations, one taken before and the other after δ; c and c' being the chronometer times corresponding to s and s', and e and $\acute{e}$ the chronometer errors derived therefrom.

Now deduct s first from s', and then from δ; the resulting differences $(s'—s)$ and $(\delta—s)$ stand for the mean solar or sidereal intervals, the former between s' and s, and the latter between δ and s. Again the rate produced during the interval $(s'—s)$ is $\acute{e} \backsim e$, whence the rate for $(\delta—s)$ will be the fourth term to the following proportion:

$$(s'—s) : (\acute{e} \backsim e) :: (\delta—s) : ——$$

The fourth term being computed and applied to e, will furnish the chronometer error ϵ at the given time δ. Correcting δ by the error so found, there will result the required chronometer time t.

In the foregoing explanation the given terms s and s' and that required to be reduced δ, are supposed to be of the same denomination. But in practice this may not always be the case. For instance, s and s' may be *mean solar*, and δ a *sidereal time*, or *vice-versâ*; that is, s and s' being sidereal, and δ a mean solar time. In the former case, δ must be converted to *mean solar*, and in the latter to *sidereal time*, after which the necessary reduction may be made as directed above.

CHAPTER VI.

On the Method of Determining the Azimuth of the Referring Mark from an Observation taken to a Circumpolar Star, at the time of its Maximum Elongation.

When the north polar distance of a star falls short of the latitude of a place, it becomes what is called a circumpolar star at that place,—that is to say, a star which never sets, but is continually above the horizon, describing in the course of a sidereal day, a small circle round the pole, of greater or less magnitude, according to the length of the star's north polar distance.

In the diurnal circular path, above adverted to, of a circumpolar star, there are two points, one of which is furthest east, and the other furthest west from the North Pole. When the star arrives at the one or the other of those points, it is said to be at its maximum elongation, that to the east, being called the *eastern*, while that on the west is styled the *western elongation.*

When a circumpolar star arrives at its maximum elongation, it becomes on account of its slow azimuthal motion a very convenient object for observation for the purpose of determining the azimuth of the referring mark. For this purpose, the elements which are required to be known with reference to it are three in number, and they are as follows :—1st, the time of the elongation; 2nd, the star's azimuth; and 3rd, its altitude. The formulæ whereby these elements may be computed are given below:—

1st. *For Horary Angle,* ... $\cos P = \tan \varpi . \tan \lambda$

2nd. *For Azimuth,* .... $\sin A = \sin \varpi . \sec \lambda$

3rd. *For Altitude,* .... $\sin Alt. = \sec \varpi . \sin \lambda.$

In these expressions, ϖ stands for the star's north polar distance, and λ for the latitude of the place; *P*, *A*, and *alt.* being the required elements, the first, the star's horary angle, the second, its azimuth, and the third, its altitude.

Type of Computation.

a Ursæ Minoris observed at Kaliana, G. T. Station, on the afternoon of the 5th October, 1836.

$*$'s North Polar distance ϖ = 1° 33′ 43″·74

Latitude of Kaliana .... λ = 29 30 49.

Tan ϖ . 8·4357077	*Sin* ϖ . 8·4355163	*Sec* ϖ .. 0·0001615
Tanλ .. 9·7528827	*Sec*λ .. 0·0603616	*Sin*λ .. 9·6925211
Cos P .. 8·1885904	*Sin A* .. 8·4959079	*Sin Alt.* 9·6926826
P = 89° 6′ 55″·56	A = 1° 47′ 42″·55	*Alt.* = 29° 31′ 32″·43

When the horary angle is brought out in the way directed above, it will be in space, and will require to be converted into time. When this reduction is made, the resulting element added to or subtracted from the star's apparent right ascension will furnish the sidereal time,—in the former case of the western, and in the latter of the eastern elongation, which sidereal time may be converted to corresponding mean solar or chronometer time, as may be required, agreeably to the precepts given in Chapter V.

EXAMPLE.

Thus the horary angle, computed above, converted to time, will be $5^h\ 56^m\ 27^s.70$, and the star's apparent right ascension is $1^h\ {}^m\ 42{\cdot}72^s$; hence the sidereal times of the eastern and western elongations are $19^h\ 5^m\ 15^s.02$ and $6^h\ 58^m\ 10^s.42$, the same in mean solar time being $6^h\ 8^m\ 20^s$, $17^h\ 59^m\ 19^s$.

After the preliminary computation has been gone through, the next step is to take the required observation upon the circumpolar star, which may be done in the following manner:—About a quarter of an hour before the maximum elongation, plant the theodolite over the station dot, and perform thereon all the necessary adjustments. This done, take a reading to the referring mark. To this reading apply the angle* between the referring mark and the star, the resulting reading is obviously the azimuthal direction of the latter. When the instrument is set in this direction, and the telescope raised to the computed altitude, intersect as accurately as possible the star, which will be found near the cross wires. The maximum elongation not having as yet occurred, the star will be receding from the meridian, continue therefore intersecting it, until it reaches the utmost limit in the direction of its motion. When an intersection has been obtained at that limit, read off the instrument, after which take a second observation to the referring mark.†

The mean between the two readings of the referring mark may be treated as one reading, and the difference between it and the reading of the star will be the angle between the two objects observed, which angle being applied to the star's computed azimuth, will furnish the azimuth of the referring mark.

* It will be sufficient if this angle is known to within 2′ or 3′, and a result within this limit may always be obtained in the following manner:—Determine an approximate azimuth of the referring mark by an observation upon the sun as explained in the preceding Chap. II: add this azimuth to the star's azimuth, or subtract one from the other, according as the referring mark and the star lay on different or on the same side of the meridian: the sum or difference so derived will be the angle sought.

† This process will not be necessary when a good chronometer is at hand, because the time of the maximum elongation being then accurately indicated, an observation on the star at that instant will furnish the angle sought.

The observation above mentioned appertains to one of two faces of the zero, to which the instrument was set. On the succeeding night, a similar observation will require to be made on the opposite face of the same zero. In this way all the zeros being disposed of, the mean of all the observations will be the true azimuth of the referring mark.

Whenever practicable, the azimuth of the referring mark ought to be derived from two elongations of a star. When this can be done, the deduced azimuth will not be affected by the errors which may exist in the given latitude and north polar distance. On the other hand, an azimuth obtained from a single elongation will be impregnated with the full effect of those errors.*

It ought to be mentioned at this place that, prior to the year 1832, all the azimuths in the Great Trigonometrical Survey of India were determined by observations taken to stars at their maximum elongations. The method is susceptible of great accuracy, as will appear from an inspection of the following Table, extracted from Col. Everest's Indian Arc, published in 1830, and containing a record of the observations made on α Ursæ Minoris at the time of its western elongation, together with the azimuths of the referring mark deduced therefrom.

---

* As the apparent north polar distance of a star is continually changing its value from one day to another, it is clear that the horary angle and the azimuth, which are derived from it, will require a fresh and independent computation for every elongation observed. This is a tedious process, which may be easily avoided by using the following differential formulæ:

$$\delta P \text{ (in seconds of time,)} = -\frac{\tan alt.\ \sec \varpi}{15} \cdot \delta\varpi$$

$$\delta A \text{ (in seconds of space,)} = \sec \lambda .\ \operatorname{cosec} P . \delta\varpi$$

wherein $\delta\varpi$ stands for the variation (supposed to be given in seconds) which has taken place in the star's north polar distance since the first day's observation, δP, δA being the corresponding alterations, the former in the horary angle, and the latter in the azimuth: compute therefore the azimuth A, the horary angle P, and the altitude of the star for the first elongation observed, and then making $\delta\varpi$ the difference between the north polar distance on the first and any subsequent day of observation; deduce δP and δA, and apply them respectively to P and A, the resulting terms will obviously be those which appertain to the star's polar distance $\varpi \pm \delta\varpi$.

As to the signs of δP and δA, it will be remembered that the former will be negative and the latter positive, when the star's north polar distance is increasing; and that they will be of the contrary affections when the north polar distance is diminishing.

OBSERVED AZIMUTHS.

KALIANPUR, NOVEMBER, 1824.

α Ursæ Minoris—Western Elongation.

Time.	Observed Objects.	3-Feet Theodolite. Micrometer A.	Micrometer B.	Mean.	Angles.	Star's Computed Azimuths.	Deduced Azimuths of Referring Mark East.
		° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	″
1824. 13th November, h. m. s. 15 44 10·5	Star	150 1 50	150 2 2	150 1 56	1 46 43·5	1 46 29·63	13·87
	Referring Mark .	151 48 31	151 48 48	151 48 39·5			
14th November, 15 39 51	Star	136 4 46·5	136 5 6	136 4 56·25	1 46 55·75	29·26	26·49
	Referring Mark .	137 51 38	137 52 6	137 51 52			
15th November, 15 36 46	Star	116 16 29	116 16 58	116 16 43·5	1 46 53·5	28·90	24·60
	Referring Mark .	118 3 26	118 3 48	118 3 37			
16th November, 15 32 41	Star	96 23 12	96 23 39	96 23 25·5	1 46 54·75	28·56	26·19
	Referring Mark .	98 10 7·5	98 10 33	98 10 20·25			
17th November, 15 30 7·45	Star	76 20 55·5	76 21 20	76 21 7·75	1 46 53·25	28·24	25·01
	Referring Mark .	78 7 47	78 8 15	78 8 1			
18th November, 15 24 44	Star	56 23 26	56 23 52	56 23 39	1 46 43·0	27·91	15·09
	Referring Mark .	58 10 9	58 10 35	58 10 22			
19th November, 15 21 20	Star	36 18 55·5	36 19 15	36 19 5·25	1 46 40·25	27·58	12·67
	Referring Mark .	38 5 37	38 5 54	38 5 45·5			
20th November, 15 15 33	Star	16 13 55	16 14 16	16 14 5·5	1 46 46·0	27·25	18·75
	Referring Mark .	18 0 44	18 0 59	18 0 51·5			
21st November, 15 9 17	Star	176 10 57	176 11 17	176 11 7	1 46 45·75	26·92	18·83
	Referring Mark .	177 57 40·5	177 58 5	177 57 52 75			

CHAPTER VII.

ON THE METHOD OF DETERMINING THE AZIMUTH OF THE REFERRING MARK, FROM OBSERVATIONS TAKEN TO A CIRCUMPOLAR STAR NEAR THE TIME OF ITS MAXIMUM ELONGATION, AS PRACTISED IN THE GREAT TRIGONOMETRICAL SURVEY OF INDIA, ALSO ON THE MODE OF FINDING THE VARIATION OF THE NEEDLE.

IT is clear that when a circumpolar star is taken in the way described in the preceding chapter, only one observation can be made at one elongation. This is a great limitation of the powers of the observer. To extend this power, the procedure, introduced by Col. Everest into the Trigonometrical Survey, consists in taking a circumpolar star, a certain number of times *before* and *after* its greatest elongation; and in subsequently reducing these observations to the star's maximum position, and then working out the azimuth as before explained. In addition to a theodolite, a good chronometer is absolutely necessary to carry this process into effect.

Col. Everest's method of taking a circumpolar star may be described follows :—About an hour before the maximum elongation of a star lected for observation, the observer will adjust the theodolite over the station dot, and set it to a given zero. When this is effected, take a reading to the Referring Mark; and then having fixed the telescope to the star's computed altitude, move it azimuthally by the hand, until the star appears in the field of vision. Now fasten the horizontal clamp, and by the usual appendages of slow motion, place the star in the upper angle of the wires, if it is descending, or in the lower angle, if it is ascending. This done, call out to the assistant to count the seconds' beats of the chronometer, at the same time watch the star's approach to the intersection of the wires. As soon as the star comes over the said intersection,* mark the time, and then read off the azimuthal limb. Now loosen the horizontal clamp, and after moving the telescope by the hand a few degrees in advance, bring it back to the star, and then take

* To do this well, will require a little practice. After two or three trials, the observer will know the direction of the star's motion, and when he has acquired this, he will intuitively place the cross-wires, so that the star may at once come upon it.

NOTE.—*In modern observations, the Transverse level is read after intersection of the star.*

another intersection thereon in the same way as before; after which lower the telescope and make an observation on the Referring Mark. This will complete a set of observations on one face of the theodolite. As to the manner of treating these observations, it will perhaps be useful to note that one angle will be derived from the first pair of the readings of the Referring Mark and the star, while another angle will be obtained from the second pair of the readings taken on the same objects.

When observations on one face of the instrument have been made as described above, the observer will now reverse the face of the theodolite, and take a second set of intersections similar to the first. In this manner, when he has done with one face, he will revert to the other, until, as may be required, four or six changes of face are regularly gone through. This will complete observations on one zero at a given elongation of a circumpolar star.

The system of changing the zero of a theodolite as explained at pp. 480-481 will require to be practised in circumpolar star observations in the same rigorous manner as in observations on terrestrial signals; for the graduation errors which that procedure is supposed to correct, have a tendency to vitiate equally the two classes of observations, and in both cases, therefore, they must be eliminated by similar arrangements and artifices. When a circumpolar star is being observed, it is convenient to adjust the changes of zero by the Referring Mark.

The following is a specimen of the Angle Book for registering circumpolar star observations.

SPECIMEN OF THE ANGLE BOOK.

a Ursæ Minoris at Eastern Elongation, observed at Kaliana, G. T. Station, on the afternoon of the 5th October 1836, with a three feet Theodolite.

Objects.	Face.	Micrometer Readings. A.	B.	C.	D.	E.	Mean.	Angles.	Chronometer Times.
		° ′ ″	″	″	″	″	° ′ ″	° ′ ″	h. m. s.
Referring Mark	R	189 1 5·7	11·9	37·9	22·2	15·0	189 1 18·54		
a Ursæ Minoris		190 48 9·2	16·7	41·4	25·2	20·0	190 48 22·50	1 47 3·96	5 58 27
a Ursæ Minoris	R	190 48 14·3	23·5	46·9	31·1	24·7	190 48 28·10	1 47 8·50	6 0 25
Referring Mark		189 1 5·5	12·4	38·8	24·9	16·4	189 1 19·60		
Referring Mark	L	9 1 9·0	16·8	43·9	24·2	14·3	9 1 21·64		
a Ursæ Minoris		10 48 35·2	43·2	69·1	51·2	41·3	10 48 48·00	1 47 26·36	6 7 32
a Ursæ Minoris	L	10 48 38·0	45·7	71·3	55·3	45·3	10 48 51·12	1 47 29·36	6 9 36
Referring Mark		9 1 9·3	17·5	42·0	25·0	15·0	9 1 21·76		
Referring Mark	R	189 1 5·8	14·5	39·5	23·2	15·5	189 1 19·70		
a Ursæ Minoris		190 48 46·7	55·0	78·9	61·0	56·0	190 48 59·52	1 47 39·82	6 16 23
a Ursæ Minoris	R	190 48 46·3	55·0	79·3	62·9	54·1	190 48 59·52	1 47 41·36	6 19 59
Referring Mark		189 1 4·9	12·1	36·9	22·4	14·5	189 1 18·16		
Referring Mark	L	9 1 6·5	16·1	41·5	21·8	11·7	9 1 19·52		
a Ursæ Minoris		10 48 53·2	62·1	87·7	70·0	60·9	10 49 6·78	1 47 47·26	6 26 22
a Ursæ Minoris	L	10 48 52·5	60·2	85·4	67·9	60·2	10 49 5·24	1 47 45·36	6 28 58
Referring Mark		9 1 6·8	15·0	41·1	22·9	13·6	9 1 19·88		
Referring Mark	R	189 1 3·5	9·0	35·9	21·2	13·5	189 1 16·62		
a Ursæ Minoris		190 48 39·9	47·5	72·0	56·0	48·1	190 48 52·70	1 47 36·08	6 37 0
a Ursæ Minoris	R	190 48 32·7	40·2	64·0	48·2	41·0	190 48 45·22	1 47 27·18	6 39 19
Referring Mark		189 1 4·5	11·1	38·0	22·9	13·7	189 1 18·04		
Referring Mark	L	9 1 7·5	17·8	43·1	24·0	12·5	9 1 20·98		
a Ursæ Minoris		10 48 19·5	28·0	53·9	33 7	26·3	10 48 32·28	1 47 11·30	6 47 18
a Ursæ Minoris	L	10 48 12·0	21·3	46·1	26·9	18·8	10 48 25·02	1 47 2·80	6 49 15
Referring Mark		9 1 9·9	17·2	44·4	26·0	13·6	9 1 22·22		

To obtain the best angles which a theodolite is capable of furnishing, the motion of the telescope, whether proceeding from the Referring Mark to the star, or *vice versâ,* should be continuous and in one direction, never allowing the telescope, or rather the cross-wires contained therein, to pass the object to be intersected, and then be brought back to it. This mode of taking an observation, although difficult at first, is rendered very easy after a little practice.

With a view of computing these observations, the first thing to be done is the conversion of the observed chronometer times to corresponding sidereal times, the mode of executing which has been explained in Chapter V. When this reduction is made, take the difference between the sidereal time of each observation and that of the maximum elongation, and convert it into space. Let δP stand for the elements so derived.

Now δP being the interval elapsed between each observation and the star's maximum position, the term, which is now required to be known, is the azimuthal variation δA corresponding thereto. This term may be computed by the following formulæ :

1*st.*—*When the star is observed below the maximum position.*

$$\tan \delta A = \frac{2 \sin^2 \frac{1}{2} \delta P}{\sin P \cot \alpha \cos \lambda \left\{ 1 + \tan^2 \alpha \cos \delta P + \sec^2 \alpha \cot P \sin \delta P \right\}}$$

2*nd.*—*When the star is taken above the maximum position.*

$$\tan \delta A = \frac{2 \sin^2 \frac{1}{2} \delta P}{\sin P \cot \alpha \cos \lambda \left\{ 1 + \tan^2 \alpha \cos \delta P - \sec^2 \alpha \cot P \sin \delta P \right\}}$$

in which, as stated elsewhere, λ represents the latitude of the place, α standing for the star's north polar distance, and P for the horary angle at its maximum position east or west.*

These formulæ have been investigated by Babu Radhanath Sickdhar, late Chief Computer to the Great Trigonometrical Survey, and are applicable to all circumpolar stars, irrespective of the lengths of their north polar distances, and they are now used in all the rigorous computations of the Great Trigonometrical Survey.

The terms δA being computed and applied to the observed angles, we obtain the angles as if taken at the star's maximum elongation. To these angles, the star's computed azimuth being applied, the resulting elements will be the required azimuths of the Referring Mark.

* As the star *ascends* on the east side of the meridian; the observations made *before* the eastern elongation are reduced by the first formula, and those taken after are computed by the second. In the western elongation, a contrary procedure is followed, because the star is *descending;* the second formula being used in deducing the *prior,* and the first in computing the *subsequent* observations.

It will be seen that this deductive process, although suited to the requirements of a Trigonometrical Survey, will prove much too operose, if applied to an operation of a lower order. To meet the wants of the latter, therefore, we will describe an approximate method of computation, derivable from the above formulæ, and which, when applied to α Ursæ Minoris, will not produce an error of a second in the result.

This approximate process of computation is as follows:

1*st.*—Compute the following constant logarithm:

$$0{\cdot}29303 + \log.\ \sec\lambda + \log.\ \tan\varpi + \log.\ \mathrm{cosec}\ P.$$

2*nd.*—Compute as accurately as the means will allow to the nearest second, the chronometer time of the star's maximum elongation observed.

3*rd.*—Compute the chronometer interval elapsed between each observation and the maximum elongation, and convert it to minutes and decimals thereof.

4*th.*—Take the logarithm of the interval converted to minutes as directed above, double it, and add thereto the constant log., deduced according to precept 1st. The natural number answering to the sum is δA in seconds.

5*th.*—In making this computation, the logarithms used need not be carried beyond 5 decimals.

To carry this method into effect, we would recommend to the surveyor to derive his azimuths from observations made to α Ursæ Minoris alone, which is a star generally known, and of easy recognition. The chronometer time of the star's eastern or western elongation (as the case may be) being deduced, two pairs of angles may be taken before, and two pairs after that event, as described at pp. 594, 595. The corrections to these angles being computed by the approximate process, and applied, we shall have the angles at the star's maximum position. When these angles are combined with the star's computed azimuth, there will result azimuths of the Referring Mark.

Type of Computation by the Approximate Process.

Take the observations made at Kaliana, on the 5th October 1836, given at p. 619.

Constant Logarithm Computed.

Constant Log. as per Rule		°	′	″		0·29303
Latitude of Kaliana	$\lambda =$	29	30	49	*sec*	0·06036
✱'s North Polar Distance	$\varpi =$	1	33	44	*tan*	8·43573
Horary Angle	$P =$	89	6	56 (*vide* p. 589)	*cosec*	0·00005
Required Constant Log.						$\bar{2}{\cdot}78917$

δA from the following Computation applied to the Observed Angles.

Observed Angles to the nearest second.	δA	Angles reduced to the time of Maximum Elongation.
	+	
° ′ ″	″	° ′ ″
1 47 4	40	* 1 47 44
1 47 9	34	1 47 43
1 47 26	17	1 47 43
* 1 47 29	13	1 47 42
1 47 40	4	1 47 44
1 47 41	1	1 47 42
1 47 47	0	1 47 47
1 47 45	2	1 47 47
1 47 36	10	1 47 46
1 47 27	14	1 47 41
1 47 11	33	1 47 44
1 47 3	39	1 47 42

Mean Angle at the time of Maximum Elongation	1° 47′ 44″
***'s Azimuth, *vide* p. 589**	1 47 43
Azimuth of the Referring Mark West	0 0 1

Variation of the needle. The azimuth of the Referring Mark having been deduced by any of the preceding methods, a simple observation with any magnetic instrument is only necessary to ascertain at once the variation of the needle, by accurately fixing the theodolite over the station dot, and taking a series of magnetic bearings to the Referring Mark. The difference between the mean of such readings and the computed azimuth, is the required variation, which will be *east* or *west* according as the true azimuth is greater or less than the magnetic, supposing the azimuth is reckoned from north by east. Hence to obtain the true azimuth when the variation is *east,* add it to the magnetic bearing, and if *west,* subtract it. It is unnecessary to enter further into this subject beyond what is required for practical purposes. All the chief works on navigation treat of the variation of the compass in different parts of the world, and to such works the reader is referred for further information. In India the magnetic variation is about 2½ degrees *east.*

Deduction of δ A.

	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.
Observed Chronometer Times	5 58 [illegible]7	6 0 25	6 7 32	6 9 36	6 16 23	6 19 59	6 26 22	6 28 58	6 37 0	6 39 19	6 47 18	6 49 15
Chronometer time of Maximum Elongation	6 24 0	6 24 0	6 24 0	6 24 0	6 24 0	6 24 0	6 24 0	6 24 0	6 24 0	6 24 0	6 24 0	6 24 0
Chronometer Intervals ...	25 33	23 35	16 28	14 24	7 37	4 1	2 22	4 58	13 0	[illegible] 19	23 18	25 15
Chronometer Intervals reduced to the decimals of a minute	25·55	23·58	16·47	14·40	7·62	4·02	2·37	4·97	13·00	15·32	23·30	25·25
Logs of the same	1·40739	1·37254	1·21669	1·15836	0·88196	0·60423	0·37475	0·69636	1·11394	1·18526	1·36736	1·40226
Repeated	1·40739	1·37254	1·21669	1·15836	0·88196	0·60423	0·37475	0·69636	1·11394	1·18526	1·36736	1·40226
Constant Log	$\bar{2}$·78917	$\bar{2}$·78917	$\bar{2}$·78917	$\bar{2}$·78917	$\bar{2}$·78917	$\bar{2}$·78917	$\bar{2}$·78917	$\bar{2}$·78917	$\bar{2}$·78917	$\bar{2}$·78917	$\bar{2}$·78917	$\bar{2}$·78917
Logs of δ A	1·60395	1·53425	1·22255	1·10589	0·55309	$\bar{1}$·99763	$\bar{1}$·53867	0·18189	1·01705	1·15969	1·52389	1·59369
δ A in Seconds	40	34	17	13	4	1	0	2	10	14	33	39

CHAPTER VIII.

On the Methods of determining the *Latitude* of a Place.*

In the methods of computation which have already been treated of in the preceding chapters, for the determination of the error of the chronometer and of the azimuth of the Referring Mark, the latitude of the station of observation is supposed to be given. If this element can be derived from the Great Trigonometrical Survey, the best thing which the surveyor can do, is to use it at once, as it would be superior to any determination which he is likely to effect for himself with the limited means at his disposal. On the other hand, instances will frequently occur of the Trigonometrical Survey not having extended to those districts, which are being traversed over by a Revenue or Topographical operation: in such cases the required latitudes of places must be derived from observation alone. It is the object of this chapter to explain the method of making and computing such observations.

With this view we will suppose that on a fine clear morning the surveyor has arrived at the origin of his operations, furnished with a theodolite, possessing a complete vertical circle, together with a chronometer and a nautical almanac, and that he is ignorant of the geographical position of the place where he is standing, as also of the direction of the meridian, and the error of the chronometer. Under these circumstances, the first thing he will [illegible] to execute

* In the limited space allowed to the following chapters, it is not possible to describe in detail all the different methods in use for observations for Latitude and Longitude, only the most practical methods, which may be easily applied by any surveyor in the course of his operations or explorations in India, are therefore given. For the more elaborate and rigorous systems of observation and computation, see "A Manual of Spherical and Practical Astronomy" by William Chauvenet, Professor of Mathematics and Astronomy, Washington University, Philadelphia, 1871: also "Introduction to Practical Astronomy," by Elias Loomis, LL.D., Professor of Astronomy, Yale College, New York, 1865. Some valuable information may also be obtained from the paper "On observations with Theodolites and Altazimuth Instruments," by Col. J. T. Walker, R.E., &c., &c., extracted from "Hints to Travellers," published by the Royal Geographical Society, given in the Appendix, p. xlv.

is to put up the theodolite and make an observation upon the sun as directed in Chapter II., and then taking out the latitude and longitude of the place from the best map which may be within his reach, he will compute the error of the chronometer and the chronometer time of the apparent noon. This deduction will not be of a very rigorous character. This however is a circumstance which will entail no inconvenience, as the object of this process is only to ascertain the approximate time of the sun's passage over the meridian.

About a quarter of an hour before the chronometer time, computed as mentioned above, of the apparent noon, the suveryor will intersect the sun's upper or lower limb as may be convenient. As the apparent noon has not yet occurred, the sun will be ascending, he will therefore follow up the intersection of the selected limb until it reaches the highest elevation. When an observation has been obtained at that limit, he will read off the vertical circle of the theodolite.

This vertical reading will be the *meridional altitude* of the observed limb of the sun. It is however taken on one face, and will therefore be impregnated with the index error of the instrument. The amount of this error may be determined in this way. Take any fixed well-defined and high terrestrial object, and observe its elevation on both faces of the theodolite, half the difference between these elevations is the required index error, additive to the face which gives the *lower*, and subtractive from that which furnishes the *higher* altitude. The index error of the instrument may be determined before or after the sun's observation as may be convenient.

When the observed altitude has been cleared of the index error, the next corrections to be applied thereto, are refraction and parallax, the mode of computing which will be found in the Appendix. After the observed altitude has been freed from the index error, refraction and parallax, it may now be reduced to the sun's centre. This reduction is thus performed. Increase or diminish the observed altitude corrected as described above by the sun's semi-diameter according as the lower or the upper limb was intersected; the resulting arc is the required altitude of the sun's centre.

When the elevation of the sun's centre is known, it is easy to compute the latitude of the place. According as the sun's declination is south or north, add it to, or subtract it from the said elevation, the sum or difference so obtained will be an arc, the difference between which and 90° is the latitude sought.

EXAMPLE.

The sun was observed at Hatipaon on the 25th November 1838.

		°	′	″
Observed meridian altitude of the ☉'s upper limb ...	...	39	8	18
Index error	+			34
Refraction and Parallax	—		1	5
☉'s Semi-diameter	—		16	14
True altitude of the ☉'s centre	...	38	51	33
☉'s South declination	...	20	42	15
Sum	...	59	33	48
Latitude of Hatipaon	...	30	26	12

If similar observations are made for eight or ten days in succession, and wrought up in the way described above, the mean latitude resulting will be sufficiently accurate for the bringing up of the azimuth deductions.

But probably on the third or the fourth day, the error of the chronometer will be known with great nicety; in which case it will not be necessary for the surveyor to limit himself to a *single* observation of the sun per day. He may, for instance, take four altitudes *before* and four *after* the apparent noon, marking down the chronometer time of each observation. In taking the altitudes with a theodolite, he will observe one limb first, and then the other; after which the face of the instrument being reversed, he will make two other observations similar to the first. This done, he will change the face again, and observe in the same way as before. In this manner four changes of face may be gone through during an interval of twenty or twenty-five minutes, taking care that half this interval falls on one side of the apparent noon, and half on the other. In case of no theodolite being available, a good sextant may be used.

As to the manner of reducing these observations, it must be noted that the observed altitudes will, in the first instance, require to be corrected for the index error, and sun's semi-diameter. When this is done, the resulting elements will be the altitudes of the sun's centre. These not being observed on the meridian, will require to be reduced thereto in the following manner:—Take the difference between the chronometer time of each observation and that of the apparent noon, and reduce it to sidereal interval. Again convert this interval into space and designate the resulting quantity by δp.

The term δp for each observation being deduced, and the sun's declination (d), and the approximate latitude north (λ) of the place being

known, the required correction for a given altitude may be computed by the following formulæ:—

When the Declination is North.

$$x'' = \frac{2\cos d.\ \cos\ \lambda\ \sin^2\ \tfrac{1}{2}\ \delta p}{\sin 1''\ \sin\ (d \backsim \lambda)^*}$$

When the Declination is South.

$$x'' = \frac{2\cos d\ \cos\lambda\ \sin^2\tfrac{1}{2}\ \delta p}{\sin 1''\sin\ (d + \lambda)^*}$$

The correction x'' brought out in this way, will be in seconds—and when added to the given altitude will render it meridional altitude. From the meridional altitude of the sun's centre, the latitude may be computed as directed before.

As an illustration of the computation of these formulæ, take the following observations made on the Sun at Hatipaon, on the 2nd December 1838, with Gilbert's Sextant No. 1 and Hare's Chronometer:—

Index Error of the Sextant = 55″ to be applied negatively.

Objects Observed.	Observed.		Deduced Elements of the ⊙ Centre.	
	Double Altitudes.	Chronometer Times.	Altitudes corrected for Index Error.	Chronometer Times.
	° ′ ″	h. m. s.	° ′ ″	h. m. s.
⊙'s L. L.	74 44 40	21 17 0	37 38 5	21 17 30
⊙'s U. L.	75 49 30	21 18 0		
⊙'s U. L.	75 49 50	21 19 0	37 38 16	21 19 30
⊙'s L. L.	74 45 5	21 20 0		
⊙'s L. L.	74 45 25	21 21 0	37 38 21	21 21 30
⊙'s U. L.	75 49 50	21 22 0		
⊙'s U. L.	75 50 0	21 23 0	37 38 11	21 23 30
⊙'s L. L.	74 44 35	21 24 0		
⊙'s L. L.	74 45 0	21 25 0	37 37 55	21 25 30
⊙'s U. L.	75 48 30	21 26 0		

Barometer = 23·688 inches. Thermometer = 49·5

In this Table the mean of the altitudes of the sun's upper and lower limbs has been taken as the elevation of the sun's centre, the chronometer time corresponding thereto being the mean of the two observed times. This is a process which is only approximately correct, the rigorous procedure as required by the rule, consisting in the separate reduction of the individual observations to the sun's centre; a method of computation which has been

* The terms $(d \backsim \lambda)$ and $(d + \lambda)$ represent meridional zenith distances.

dispensed with in the present instance, on account of the limited accuracy of the observed data. It ought to be remarked that when two altitudes, one taken before, and the other after the apparent noon, are combined as is done in the Table, a positive error will be produced in the result. Consequently the two observations taken under the latter circumstances will require to be corrected for semi-diameter, and separately reduced.

Deduction of the foregoing observations.

Constant Log. Computed.

☉'s South Declination ...	$d = 21^\circ\ 55'\ 34''$ ...	Cos.	$\bar{1}$·96789
Approximate Lat. of Hatipaon ...	$\lambda = 30\ 26\ 12$ ...	Cos.	$\bar{1}$·93560
	$d + \lambda = 52\ 21\ 46$ ...	Cosec.	0·10133
L. 2 + L Cosec. 1″			5·61546
Constant Log.			5·61978

	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.
Observed Chronometer Times ...	21 17 30	21 19 30	21 21 30	21 23 30	21 25 30
Computed Chronometer Time of Apparent Noon ...	21 20 59	21 20 59	21 20 59	21 20 59	21 20 59
δp. Chronometer Time ...	0 3 29	0 1 29	0 0 31	0 2 31	0 4 31
δp. Sidereal Time ...	0 3 29·57	0 1 29·24	0 0 31·08	0 2 31·41	0 4 31·74
δp. Space ...	0 52 23·55	0 22 18·60	0 7 46·20	0 37 51·15	0 67 56·10
$\frac{1}{2}\,\delta p$	0 26 12	0 11 9	0 3·53	0 18·56	0 33·58
Sin $\frac{1}{2}\,\delta p$	7·88202	7·51100	7·05293	7·74095	7·99477
Sin $\frac{1}{2}\,\delta p$	7·88202	7·51100	7·05293	7·74095	7·99477
Constant Log.	5·61978	5·61978	5·61978	5·61978	5·61978
Log. x''	1·38382	0·64178	$\bar{1}$·72564	1·10168	1·60932
x''	+ 24″	+ 4″	+ 1″	+ 13″	+ 41″
Observed Altitudes	37 38 5	37 38 16	37 38 21	37 38 11	37 37 55
Reduced Meridional Altitudes ...	37 38 29	37 38 20	37 38 22	[illegible]8 24	[illegible] 36

Latitude of Hatipaon deduced.

	°	′	″
Mean Meridional Altitude	37	38	26
Refraction and Parallax		—	53
Corrected Altitude	37	37	33
☉'s South Declination	21	55	34
Sum	59	33	7
Latitude	30	26	53

What has been said regarding the sun is likewise applicable to a star. Suppose an altitude is taken to the latter in the same manner as the former is directed to be observed. This altitude being cleared of index error and refraction, and then if necessary reduced to the meridian, the latitude may be deduced therefrom in the same way as in the case of the sun.

The observations we have described above as leading to the determination of the latitude of a place, whether made on the sun or a star, are supposed to be taken on, or near the meridian. There is a method, however, whereby the latitude may be deduced from an observation on Polaris (α Ursæ Minoris) made at any time without reference to its position with regard to the meridian line. The elements required in this deduction are, *1st.* The time of the observation, and *2nd.* The observed altitude; and when these are forthcoming, the necessary computation may be easily made by the aid of the rules and tables given in the Nautical Almanac, *vide* example given at the end of this chapter. The method is simple and may be practised with great advantage in the Revenue Survey.

Whenever, however the meridian line can be traced, the observations made thereon for the determination of latitude would be preferable to all others both in point of accuracy and facility of reduction. These observations may be made with a Theodolite in this way. Place the instrument in the plane of the meridian, and take the altitude of ten or twelve stars so selected that half the number may be situated to the North, and half to the South of the zenith, none being further off than 15° from that point. The observations must be continued for a week or ten days, the face of the instrument being reversed after each observation during the night, at the same time taking care that the same star is taken on opposite faces on two successive nights. The latitude resulting from such data would be as trustworthy as could be desired.

Suppose after the completion of the observations it is discovered that the Theodolite was not adjusted to the meridian, but was set in a plane which was inclined thereto by a small angle which we shall designate by δA. It is evident that in such a case the observed altitudes are not meridional altitudes. To make them meridional however, a correction of the following form will only require to be computed for each star, and added to the observed elevation:—

$$y'' = \frac{\delta A^2 \cos\lambda \cos a}{2 \cos d \operatorname{cosec} 1''}$$

In which expression λ stands for the approximate latitude of the place, d for the star's declination and a for the observed altitude, the resulting correction y'' being in seconds.

Another method exists for determining the latitude of a place by taking the elevations of a circumpolar star at its upper and lower culmination. When such observations are made, half the sum of the elevations cleared of index error and refraction will be the latitude required. This is a method however which cannot always be conveniently practised in this country, on account of the small altitude of the circumpolar star at its lower meridional passage, when it will be often involved in the mist which surrounds the horizon.

Extract from Nautical Almanac for 1873; p. 576.

Method of determining the Latitude *by Observations of the* Pole Star *out of the Meridian.*

From the observed altitude, when corrected for the error of the instrument, refraction, and dip of the horizon, subtract 1.′

Reduce the mean time of observation at the place, to the corresponding Sidereal time, by the Table given at p. 536 (Naut. Almc., 1873). With the Sidereal time found, take out the first correction from Table, I p. 533 (Naut. Almc., 1873). If the sign be +, the correction must be *added* to the reduced altitude; but if it be—, it must be subtracted; in either case the result will give an *Approximate Latitude.*

With the Altitude and Sidereal Time of observation, take out the *second correction* from Table II, pp. 534, 535; and with the day of the month and the same Sidereal time, take out the *third correction* from Table III, p. 534, 535, (Naut. Almc., 1873.) These two corrections *added* to the *Approximate Latitude*, will give the Latitude of the place.

Example.—On March 6th, 1873, in Longitude 37° W. at $7^h\ 43^m\ 35^s$ P.M. Mean Civil Time, suppose the Altitude of the Pole Star, when corrected for the error of the instrument, refraction, and dip of the horizon, to be 46° 17′ 28″: Required the Latitude.

	h.	m.	s.
Mean Time	7	43	35
Difference Long. (37°) time ...	2	28	0
Greenwich Mean Time	10	11	35
	h.	m.	s.
Siderial Time at Greenwich Mean Noon	22	57	9
Mean Time at place of Obsn. ...	7	43	35
Acceleration (Table, p. 536) for $10^h\ 12^m$	0	1	41
Sidereal Time of Observation ...	6	42	25

	°	′	″
Corrected Altitude	46	17	28
Subtract	0	1	0
Reduced Altitude	46	16	28
With *Argument* $6^h\ 42^m\ 25^s$, *First Correction*	—	10	34
Approximate Latitude ...	46	5	54
Arguments 46° 17′ 6^h [illegible] *Second Correction*	+	1	1
Arguments March 6th, 1873 $6^h\ 42^m$ *Third Correction*	+	1	15
Latitude of the place ... N.	46	8	10

CHAPTER IX.

ON LONGITUDE.

THE Longitude of a place may be defined to be an arc of the equator intercepted between the first meridian, and that passing through the given place. The selection of the first meridian from which longitudes are measured, is entirely arbitrary. The English use the meridian of the Royal Observatory at Greenwich as the first meridian, and reckon all longitudes to the East and West thereof. On the other hand, *le premier meridien* of the French Geographers passes through the Paris Observatory, which is 2° 20′ 15″ East of the former.

The longitude of a place is as often given in space as in time, the reduction of one measure to the other, being made at the rate of 15° an hour. Thus the longitude of the Dome of the Government House in Calcutta may be indifferently stated at 88° 23′ 27″ or 5h. 53m. 33·8s. East of Greenwich, and in this proportion of space into time, the Tables on p. 569 have been constructed.

The reason of reckoning the longitude in time, is this; suppose of two places A and B, the time at A is given, it is required to determine the corresponding time at B. This is a problem of great astronomical importance, and when the difference of longitude between A and B is given in time, it may be easily solved in this way: According as B is to the East or West of A, add the difference of longitude to, or subtract it from, the given time at A, the sum or difference so obtained, will be the required time at B. Thus when it is 7h. 22m. 40s. P.M. in Calcutta, it will be 1h. 29m. 6.2s. at Greenwich.

On the converse operation to this process, are based the astronomical methods of determining the longitude of a place. For instance, if at any moment, the times at the stations A and B are known, the difference between them is the difference of longitude sought, B being East or West of A according as the time at B is greater or less than the time at A. The time at B, the observer's station, being found by any of the methods laid down in the preceding chapters, that at A or the first meridian, is the required element in the determination of the problem.

These principles being premised, we cannot do better than give the following memoranda of instruction furnished by the Astronomer Royal, Mr. Airy, to the Officers deputed to mark the boundary between the

British Territories in America and the United States of America; which instructions duly carried into effect, will give the longitudes of places with the accuracy required for all ordinary geographical purposes:—

OBSERVATIONS FOR THE ABSOLUTE LONGITUDE OF STATION.

On the Boundary Survey these were determined entirely by observing the transits of the moon, and moon culminating stars. No other method is equal to it for accuracy and simplicity combined. Though this proved to be the case, the following paper of instructions, given by Mr. Airy, the Astronomer Royal, is so valuable, that it is considered right to insert the *whole* of it, as it cannot fail to be of service to all who have to make observations for longitude:—

Observations for the Absolute Longitude of one Station.

1. The observations applicable to this determination will be the following:—
   - (α) Distances of the moon from the sun, or a star.
   - (β) Transits of the moon.
   - (γ) Zenith distances of the moon.
   - (δ) Occultations of stars by the moon.*
   - (ε) Eclipses of Jupiter's satellites.

2. (α) Lunar distances.—It is necessary to combine with these, observations of the zenith distance of the moon, and of the sun, or star; and the following order will probably be found best for observation:—

Several lunar distances to be taken with the utmost accuracy (noting the time of each by the standard box chronometer, whose error can be found by transits on the same evening.)

A zenith distance of the moon (noting time) which needs not be very accurate.
A zenith distance of the star (noting time) which needs not be very accurate.
Several lunar distances.
A zenith distance of the star.
A zenith distance of the moon.
Several lunar distances.

Taking the mean of each group of distances, and then the mean of those means, and the means of the corresponding chronometer times, it will be easy, from the observed zenith distances, to deduce the zenith distances at the second times; and thus all of observation is completed.

3. For the reduction of those distances, the accurate method only should be used.

4. It must be borne in mind that, on any night, observations ought to be made of distances from stars on both sides; that particular care should be taken to make the star sweep on the moon's limb; and that observations should be made after full moon as well as before it. In using the sextant the index error ought

---

* In former times, the lunar and solar eclipses (particularly the former) were made use of to determine the longitude of a place;—but these not being susceptible of accurate observations are no longer used for this purpose. The mode of making observations on these Phenomena are well explained in the Penny Cyclopœdia "Article Longitude." See also Chauvenet's "Spherical and Practical Astronomy," Vol. I., Philadelphia, 1871.

to be determined as near as may be to the time of observation. In using the reflecting circle, the three verniers should always be read. In using the repeating reflecting circle, the two verniers of that arm, which is read, should always be read.

5. It will probably be best to defer the reductions of the observations.

But if there is leisure, you may proceed with the following cautions, some of which are not usually considered by nautical computers. With the Greenwich time, by account, compute the moon's "Horizontal Parallax," from the Nautical Almanac (which is *equatorial* horizontal parallax) and "semidiameter," which is *geocentric* semidiameter.

For the spheroidal form of the earth, multiply the equatorial horizontal parallax by $1-e \sin^2$ latitude, or diminish it by the part expressed by $e \times \sin^2$ latitude (which in the boundary latitudes will not sensibly differ from $\frac{1}{300}$th part, or 5″ to 6″), and you have the true horizontal parallax, to be used in every part that follows.

Multiply the geocentric semidiameter by 1 + cos moon's zenith distance × sin horizontal parallax, and you have the augmented semidiameter, to be used in every part that follows.

Apply the augmented semidiameter (and also the sun's semidiameter, if the sun was the other object), to the observed distance, additively if the nearest limbs were observed, subtractively if the opposite, and you have the observed distance of centres. Call this D.

To the moon's observed zenith distance of limb apply the augmented semidiameter; and you have the observed zenith distance of moon's centre.

To take into account fully the spheroidal form of the earth, compute the "angle of the centre" for the place by the formula 11′ 25″ × sin² latitude (which for the boundary latitudes will not sensible differ from 11′ 25″), and diminish the moon's zenith distance by angle of the centre × cos azimuth from south, or increase it by angle of the centre × cos azimuth from north (if the sun be north of the East or West). When the zenith distance is so altered, call it Z.

Do the same for sun's centre and call the result ζ. If the other object were a star, ζ is simply the zenith distance, affected by angle of the centre × cosine of azimuth.

6. For the zenith distance ζ, add the refraction computed as usual, and (if the sun) subtract the parallax computed by the formula 8″·7 sin ζ, and the result is true zenith distance of sun or star. Call this ζ'.

For the zenith distance z, add the refraction computed as usual, and subtract the [illegible] computed by the formulæ, true horizontal parallax × sin z, and the [illegible] is true zenith distance of moon's centre. Call this z'.

7. Then the computation for the true distance of centres, or D', is this:—

$$\sin\frac{z+\zeta+D}{2},\ \sin\frac{z+\zeta-D}{2},\ \sin z',\ \text{and}\ \sin\zeta'.$$

Make $\cos^2\phi = -$

$$\text{—. } \sin z,\ \sin\zeta.$$

$$\text{Then } \sin\frac{D'}{2} = \sin\frac{z'+\zeta'}{2}\sin\phi.$$

This form of calculation is accurate.

8. When the corrected distance of centres is thus obtained, it is to be compared with the distances given for every three hours in the Nautical Almanac, and by

taking proportional parts among them, the Greenwich mean solar time will be found. Then I recommend that this Greenwich mean solar time be converted into Greenwich sidereal time, and the difference between this and the sidereal time of observation at the place will be the longitude of the place.

9. (β) Transits of the moon;—a very simple and tolerably accurate method; but as only about eight observations can (usually) be taken in a month, and as the moon can be observed at no time but on the meridian, it will not be safe to rely upon it, except in a residence of many months' continuation.

10. The process of observing is simply to place the transit instrument in good adjustment, and to observe transits of the moon's bright limb, of clock's stars, and of stars given in the section "moon culminating stars" of the Nautical Almanac. Then inferring the clock error either from the clock stars or from the moon culminating stars, and applying this clock error to the observed time of transit of the moon's limb, you have the Right Ascension of the moon's limb at passage.

11. To compute from this the longitude. First it must be remarked, that in the section of the Nautical Almanac, the Right Ascension of the bright limb only at transit at Greenwich is given; but as the duration of semidiameter's passage is given, by adding or subtracting twice this quantity, you may obtain the right ascension of the other limb at transit at Greenwich. Thus in the following computations you will be able to collect Right Ascensions at Greenwich transit all for the $1L$, or all for the $2L$, according as the $1L$ or the $2L$ is observed at the place. Having formed these (if necessary) take the Right Ascension for the Greenwich transit corresponding to the observation, for the preceding day, for the following day, and for the lower passages which fall between them; place them in proper order, and take their differences as far as the fourth difference—thus:

		Differences.			
		1st.	2nd.	3rd.	4th.
Preceding day...	A_{-2}				
		Δ'_{-1}			
Lower passage preceding	A_{-1}		Δ''_{-1}		
		Δ'_0		Δ'''_{-1}	
Corresponding day...	A_0		Δ''_0		Δ''''
		Δ'_1		Δ'''	
Lower passage following	A_1		Δ''_1		
		Δ'_2			
Following day...	A_2				

Form the co-efficients $e = \dfrac{\Delta''''}{24}$

" " $d = \dfrac{\Delta''_{-1} + \Delta'''_0}{12}$

" " $c = \dfrac{\Delta''_0}{2} - e$

" " $b = \dfrac{\Delta'_0 + \Delta'_1}{2} - d$

Then the right ascension of moon's limb at transit in west longitude L will be

$$\underset{0}{A}+b\times\left(\frac{L}{12^h}\right)+c\times\left(\frac{L}{12^h}\right)^2+d\times\left(\frac{L}{12^h}\right)^3+e\times\left(\frac{L}{12^h}\right)^4$$

12. As the longitude of the station by account will not be greatly in error, the easiest method will probably be to assume two values for L, one five minutes greater, and the other five minutes less, than the longitude by account (or when more accurately known, one one minute greater and one one minute less). The logarithms of $\frac{L}{12^h}$, &c., for those two values can be prepared, and will always be ready. Then compute from the last formula the right ascension on each assumption, find the change produced by ten minutes or two minutes of longitude, and find by proportional parts what alteration must be applied to the smaller longitude, in order that the right ascension by fromulæ may agree with right ascension by observation in 10.

VERY GREAT CARE must be used throughout this operation, to apply the *signs* STRICTLY ACCORDING TO THE RULES OF ALGEBRA.

13. (γ.) Longitude by zenith distances of the moon. This is a very good method provided the observations be made not very far from 6^h sidereal time (whatever may be the season of the year). It would fail if the sidereal time were near 18^h.

Thus in spring (equinox) the most favourable time of day would be an hour or two before or after six in the afternoon.

In summer (solstice) an hour or two before or after noon.

In autumn (equinox) an hour or two before or after six in the morning.

In winter (solstice) an hour or two before or after midnight.

The age of the moon is of little importance, provided that sometimes the preceding limb, and sometimes the following limb, is observed.

14. For the observation, I recommend that the altitude and azimuth instrument be well adjusted, and that the transits of the moon's limb, in its sloping upward or downward motion, be observed over all the horizontal wires, and that the mean of these times of transit be held to apply to the observation on the middle horizontal wire. (If it is certain that the wires are truly horizontal, the instrument should be kept unmoved, if this is not certain, the horizontal tangent screw should be used to make the moon pass each wire at its middle.) Then read the microscopes and levels, reverse, and do the same again. Thus the apparent zenith distance of limb will be known with great accuracy at a certain chronometer time. The chronometer error being ascertained from observation of stars, the sidereal time will be known.

15. Compute the refraction and the parallax (the latter by the formula, true horizontal parallax × sine apparent zenith distance of limb, corrected by the quantity angle of centre × cosine azimuth,) and applying them to the apparent zenith distance of limb (adding refraction subtracting parallax), you have geocentric zenith distance of limb. Apply to this the semidiameter as taken from the Nautical Almanac, and not augmented, and you have the geocentric zenith distance of centre.

16. The longitude by account being nearly known, assume two longitudes, one greater and one less. For each assumption, apply the longitude to the sidereal

time at the place, which gives the sidereal time at Greenwich. Convert this into mean solar time at Greenwich; with this mean solar time and the hourly ephemeris of the Nautical Almanac, compute the moon's right ascension and N. P. D. by simple proportion of the hourly change. Then proceed to find the hour angle, exactly as if it were a star, using the geocentric zenith distance of centre, the co-latitude of the place, and the N. P. D. just computed. Apply the hour angle to the right ascension, and thus obtain the computed sidereal time; obtaining *two* computed sidereal times from the *two* assumptions of longitude, you will find (as in other cases) what correction must be applied to the smaller longitude, in order to make the computed sidereal time agree with sidereal time at the observation of the moon.

17. (δ.) Longitude by occultations of stars by the moon. Suppose the disappearance of a star behind the moon, or the reappearance of a star from behind the moon, has been observed, and the chronometer time noted (the calculation is precisely the same for disappearance or reappearance), correct the chronometer for its error, and thus the true sidereal time at the place is found.

18. Assume two values of longitude, one greater and one less than the reputed values, and by applying these to the sidereal time, form the sidereal times at Greenwich on the two assumptions, and convert them into mean solar times at Greenwich. With these mean solar times compute (by the hourly ephemeris) the right ascension and N. P. D. of the moon's centre on each assumption; also the equatorial horizontal parallax and the semidiameter, and from the equatorial horizontal parallax obtain the true horizontal parallax as in 5.

19. The latitude of station to be used in the following computations is the geocentric latitude, which will be found generally by diminishing the astronomical latitude by the angle of the centre, and which in the boundary latitudes, viz., 45° to 48°, will be found by diminishing the astronomical latitude by 11′ 25″.

20. Take from the Nautical Almanac, section occultations—elements, the right ascension and N. P. D. of the star whose occultation has been observed. From the right ascension and time find the hour angle. Put θ for the hour angle and δ for the N. P. D. Then determine a new right ascension, θ_1, and a new N. P. D., δ by the following equations:—

$$\theta-\theta'=\frac{\sin\theta\times\text{true hor. par.}\times\text{cosine latitude}}{\sin\delta'}.$$

$$\text{1st No.}=\frac{\sin\delta\times\sin\theta\times\text{true hor. par.}\times\text{sine latitude}}{\text{sine}\tfrac{1}{2}(\theta+\theta')}$$

$$\text{2nd No.}=\frac{(\theta-\theta')\times\text{sine}\,(\delta+\delta'-180^\circ)}{2\tan\tfrac{1}{2}(\theta+\theta')},$$

$$\delta-\delta'=\text{1st No.}+\text{2nd No.}$$

21. These equations are to be solved by successive substitution. Two substitutions will usually be sufficient. Thus—first assume δ' to be the same as δ, and from the first equation determine θ'. Use this in the two other equations, and you will get 1st No., 2nd No., and δ', very nearly. Use this new value of δ' in the first equation and you will get $\theta-\theta'$ much more accurately: then by means of the other two, δ' can be got still more accurately; and so on again if you think fit.

22. With this new hour angle, θ', and the sidereal time, determine a new right ascension; then calculate the following quantity:—

Computed semidiameter of moon—

$$\sqrt{\left\{\overline{\delta' - \text{N. P. D. of moon's centre}}\,\right|^2 + \sin\delta' \sin \text{N. P. D. of moon's centre}\ \overline{\text{new R. A.} - \text{R. A. of moon's centre}}\,\Big|^2\right\}}$$

This is to be computed on the two assumptions for longitude (which have given two right ascensions and N. P. D. of moon's centre).

23. The computed semidiameter ought to agree with the Nautical Almanac semidiameter found in 18. If neither of the two assumptions of longitude makes it do so, one of them must be altered by a proportional part of their difference, found in the same manner as in other cases where two longitudes are tried.

24. (ϵ). Longitude by eclipses of Jupiter's satellites—a very rough method. The observation is merely to note the last instant, or the first instant (according as it is disappearance or reappearance) of the satellite. The computation is merely to correct this for chronometer error, so as to obtain sidereal time, and to compare this with the Greenwich sidereal time given in the Nautical Almanac.

25. In regard to the effects of errors of observation, the following remarks should be borne in mind:—

A certain error of time in taking a lunar distance produces that same error in the deduced longitude. An error in the measure of one second produces about two seconds of time in the longitude.

An error of one second of time in a lunar transit produces about thirty seconds' error in the longitude.

An error of one second of time in a lunar zenith distance will produce *at least* thirty seconds of time error in longitude, sometimes considerably more. An error of one second in zenith distance produces *at least* two seconds of time in longitude, sometimes considerably more.

An error of one second of time in an occultation produces one second of time in the longitude.

The same in the observations of eclipses of Jupiter's satellites.

In illustration of the part (β) transits of the moon, the following observations and calculations made at the station of Lake Memphramagog, in Canada, are given.

The transits of the stars and the moon's bright limb are the mean of the five wires without any correction (which is unnecessary) for azimuthal error.

LAKE MEMPHRAMAGOG, 1845.

Calculations for Longitudes from observed Lunar Transits.

Values of $\left(\frac{L}{12h}\right)$ $\left(\frac{L}{12h}\right)^2$ &c., assuming the Longitudes at 4h. 48m. and 4h. 49m.

$\left(\frac{L}{12h}\right) = \frac{288\text{ M.}}{720} =$ Log. 288 : 2·459392; „ 720 : 2·857332; $\bar{1}$·602060

$\left(\frac{L}{12h}\right)$ Log. 289 M. = 2·460897; „ 720 = 2·857332; $\bar{1}$·603565

$\left(\frac{L}{12h}\right)^2 =$	$\bar{1}{\cdot}204120$	... $\left(\frac{L}{12h}\right)^2 =$	... $1{\cdot}207130$
$\left(\frac{L}{12h}\right)^3 =$	$\bar{2}{\cdot}806180$	... $\left(\frac{L}{12h}\right)^3 =$	... $\bar{2}{\cdot}810695$
$\left(\frac{L}{12h}\right)^4 =$	$\bar{2}{\cdot}408240$	... $\left(\frac{L}{12h}\right)^4 =$	... $\bar{2}{\cdot}414260$

AUGUST 14, 1845.

	μ' Sagittarii. H. M. S.		A. S. C. 2125. H. M. S.		H. M. S.
Tt.	18 14 49·46	Tt.	18 30 41·1	☽'s Transit	19 23 47·18
R. A.	18 4 33·87	R. A.	18 20 25·89	Chron. fast	10 15·40
	10 15·59		10 15·21	☽'s R. A. at Passage	19 13 31·78
	10 15·21				
2)	80				
	10 15·40				

	H. M. S.	M. S.	S.	S.	S.
Preceding Day	... 17 55 40·57				
		+ 32 31·50			
Lower Passage Preceding	... 18 28 12·07		− 6·52		
		+ 32 24·98		− 11·43	
Corresponding Day	... 19 0 37·05		− 17·95		+ 2·10
		+ 32 7·03		− 9·33	
Lower Passage Following	... 19 32 44·08		− 27·28		
		+ 31 39·75			
Following Day	... 20 4 23·83				

$$e = \frac{\Delta'''}{24} = + \frac{2{\cdot}10}{24} = + {\cdot}087$$

$$d = \frac{\Delta''_{-1} + \Delta'''_{0}}{12} = - \frac{20{\cdot}76}{12} = - \overset{\text{S.}}{1{\cdot}730}$$

$$c = \frac{\Delta''_0}{2} - e = - \frac{17{\cdot}95}{2} - e = - 8{\cdot}975 - (+ {\cdot}087) = - \overset{\text{S.}}{9{\cdot}062}$$

$$b = \frac{\Delta'_0 + \Delta'_1}{2} - d = + \frac{64\ 32{\cdot}01}{2} - d = + 32\ 16{\cdot}005 - (- 1{\cdot}730) = + \overset{\text{M.}\ \ \text{S.}}{32\ 17{\cdot}735}$$

60

1937·735

	H. M. S.		H. M. S.	
R. A. =	19 0 37·05	R. A. =	19 0 37·05	
	+ 1937·735 =	3·294		3·287294
		1·602060		1·603565

$+ b \times \left(\frac{L}{12h}\right) = + 0\ 12\ 55{\cdot}90$ $2{\cdot}889351 + 0\ 12\ 57{\cdot}78 = 2{\cdot}890859$

$-9{\cdot}062 = 0{\cdot}957224$ $0{\cdot}957224$

$\bar{1}{\cdot}204120$ $\bar{4}{\cdot}207130$

$+ c \times \left(\frac{L}{12h}\right)^2 = -\ 0\ 0\ 1{\cdot}45$ $= 0{\cdot}161344 - 0\ 0\ 1{\cdot}46 = 0{\cdot}164354$

$-1{\cdot}730 = 0{\cdot}238016$ $0{\cdot}238016$

$\bar{2}{\cdot}806180$ $\bar{2}{\cdot}810695$

$+ d \times \left(\frac{L}{12h}\right)^3 = -\ 0\ 0\ 0{\cdot}11$ $\bar{1}{\cdot}044226 - 0\ 0\ 0{\cdot}11 = \bar{1}{\cdot}048741$

$+ e \times \left(\frac{L}{12h}\right)^4 = +\ 0\ 0\ 0{\cdot}00\ 0{\cdot}087$ $= \frac{2}{2}$ $+\ 0\ 0\ 0{\cdot}00$ $\frac{2}{2}$

	19 13 30·58		19 13 33·26
☽'s R. A. at	19 13 31·78	Passage.	19 13 30·58
	0 0 01·20		0 0 02·68

s. 2·68 : s. 60 : : s. 1·20

1·20

2·68) 72·00 (26·86

536

·1840

1608

·2320

2144

·1760

H.	M.	S.
4	48	0
0	0	26·86
4	48	26·86

Longitude = 4 H. 48 M. 26·86 S.*

The following account is given of the method employed in determining the longitude of Kashghar by Captain Trotter, R.E., Deputy Superintendent, Great Trigonometrical Survey of India, in the Geographical Section of the Report of the Mission to Yarkand from India, under Sir Douglas Forsyth, K.C.S.I., in 1873-74 :—

"The method of observation employed in the determination of absolute longitudes was that of lunar zenith distances, as being best adapted to the largest instrument carried with the expedition, *viz.*, a six-inch transit theodolite, with

* From the Corps Papers and Memoirs on Military Subjects of the Royal and East India Company's Engineers, vol. i., pp. 311, 318.

micrometer eye-piece. This method of observation has not hitherto occupied a prominent position in English astronomical works, and as the results at Kashghar cannot but be considered satisfactory, I have thought advisable to enter somewhat at length into the subject and to give an example of the computation of a single night's observations there, drawn up on a form specially prepared from Chauvenet's *formulæ* by J. B. N. Hennessey, Esq., of the Great Trigonometrical Survey.

"The subject is gone into somewhat fully in an article furnished by Colonel Walker, R.E., in *Hints to Travellers*, a publication of the Royal Geographical Society (3rd Edition, December 1871), to which the reader is referred.*

"The instrument employed at Kashghar was furnished with two micrometers, each moving a separate wire, the eye-piece being so arranged that the micrometer wires may be placed parallel either to the fixed vertical or to the fixed horizontal wire of the diaphragm, according as transits or zenith distances are required to be observed.

"The distance between the micrometer and centre wires is adjustable at pleasure, and may be set according to the rate of motion of the celestial body observed. A complete observation of the moon on one face of the instrument consists in noting the chronometer times of passage of the moon's limb across each of the wires in succession, and the corresponding reading of the vertical verniers; a complete pair of observations on both faces gives altogether six *times* and four *readings* of the vertical arc. The readings of the ends of the bubble of the level attached to the telescope, object and eye ends being alternately directed towards the object observed, give a correction to be applied to the mean of the readings of the vertical arc which gives a final zenith distance corresponding to the mean of the six chronometer times.

"In the example I have given it took me just three quarters of an hour to observe ten complete pairs of zenith distances as before described. A quarter of an hour may be allowed for the observation of three pairs of zenith distances to a star for time prior to the observations to moon, and an equal time for similar observations after. To complete observations in the time abovementioned, however, the observer must be thoroughly familiar with his instrument, must have a good recorder, and have his lamps and apparatus in perfect order.

"The weak point of the system is that it is only applicable at certain times when the moon is favorably situated for observation; still, however, even in this respect it contrasts favorably with all other methods, excepting that of 'lunar distances,' for determining longitudes. I give some rules which have been laid down on this subject by Colonel Walker in the *Hints to Travellers*, modified by subsequent experience: they may, I hope, be of use to future explorers.

"'Take pairs of observations of zenith distance on a star for the determination of 'the local time and chronometer error, then take other pairs of observations of 'zenith distance on the moon, in each instance adopt the mean of the chronometer 'times as that of the 'complete observation' of zenith distance. Both moon and 'star should be as nearly easterly or westerly as possible, and not very near (say 'within 10° of) the horizon. The operations should commence and close with star-'observations, in order that the chronometer rate may be duly ascertained and 'allowed for. The effect of instrumental errors will be materially reduced when

* See Appendix, p. lii.

'the stars and the moon are on the same side of the meridian and at nearly the 'same zenith distance; if time permits, observations should be taken both east and 'west of the meridian, and both before and after full moon. In north latitudes, 'when the moon is going from south to north in declination on any day, she is 'most favorably situated for observing when west of the meridian; if moving in 'declination from north to south, she should be observed east of the meridian.

"'The best time for observation is *when the direction of the proper motion* of the 'moon is towards the zenith of the observer. The sidereal time, when this occurs, 'may be readily found, graphically, by drawing on a chart of the heavens a tangent 'to the moon's orbit at some point near the mean position of the moon, on the day 'of observing, and producing it to cut the declination circle passing through the 'observer's zenith; then the hour circle passing through the point of intersection 'gives the sidereal time of observation. For practical purposes it will suffice to 'drop a perpendicular from the point indicating the moon's mean position on to the 'ecliptic, and drawing through that point a line at right angles with the perpendi- 'cular, and prolonging it to cut the declination circle. It will be found that the 'most favorable times occur when the moon is on the observer's prime vertical, and 'the least favorable when she is on the meridian.

"'Whenever possible a few observations should be taken daily on several days 'rather than a large number on a single day.'"

Observations for Time; and Resulting Chronometer Corrections employed in determining Local Mean Time for the calculation of Longitude from Lunar Zenith Distance.

Place of Observation.	Astronomical Date.	Object Observed.	East or West of Meridian.	Elements employed in computation of Refractions. Baro.	Ther.	No. of pairs of Observations.	Mean of observed Z Ds corrected for dislevelment.	Mean of Chronometer Times.	Computed correction to Chronometer Time to find corresponding Mean Time.
	18[illegible]			In.	°		° ′ ″	h. m. s.	h. m. s.
KASHGHAR (Yangi-Shahr).	6th D[illegible]	γ Geminorum	E.	25·7	24	3	53 8 29	10 8 32·0	—0 22 22·0
	,, ,,	β ,,	,,	...	...	3	41 15 19	11 43 27·3	—0 22 21·6
	7th	,, ,,	,,	25·8	...	3	47 21 5	11 7 57·6	—0 22 19·2
	,, [illegible]	α Leonis	,,	...	15	3	66 7 53	12 40 2·6	—0 22 19·3
	27th [illegible] ,,	α Androm.	W.	25·5	20	3	42 46 7	9 21 31·1	—0 22 19·2
	28th [illegible] ,,	α Arietis	,,	25·6	18	2	50 11 58	11 39 11·7	—0 22 20·7
	,, [illegible] ,,	,, ,,	,,	...	...	2	52 26 18	11 50 45·6	—0 22 20·1

*Observations of Lunar Zenith Distances and Resulting Determination of Longitude.**

Place of Observation.	Astronomical Date.	☾ E or W. of Meridian.	☾ Upper or Lower Limb.	Mean of each pair of observed Z. Ds corrected for dislevelment.	Mean of Chronometer Times.	Resulting Longitude. Value from each pair of Observations.	Resulting Longitude. Mean of the day's Observations.	Approx. Sidereal Time of Observations.
	1873.			° ′ ″	h. m. s.	h. m. s.	h. m. s.	h. m.
KASHGHAR (Yangi-Shahr). The station of observation was in the centre of the Embassy Buildings.	28th Dec.	W.	L.	46 56 38	10 25 34·8	5 4 42		
				47 43 14	30 10·9	4 34		
				48 33 30	35 5·8	4 28	5 4 36	5 15
				49 43 0	41 48·7	4 41	or	
				50 17 58	45 10·3	4 40	° ′ ″	
				51 17 43	50 52·7	4 36	76 9 0	
				51 53 54	54 18·5	4 42		
				52 45 57	59 13·6	4 36		
				53 23 12	11 2 44·2	4 23		
				54 25 40	8 34·2	4 34		

* Observations were taken at Kashghar on six nights in December 1873 and January 1874, with the following results:—

DATE.	RESULTING LONGITUDE.	
6th December, 1873	... ... 76° 2′ 45″	Arithmetical mean. 76° 6′ 47″·5
7th " "	... ... 76 2 30	
27th " "	... ... 76 5 0	
28th " "	... ... 76 9 0	
29th " "	... ... 76 11 45	
31st January 1874	... ... 76 9 45	

In addition to the foregoing methods, it may be useful to lay down the process of determining the difference of longitude between two places by a chronometer. Suppose *A* and *B* to be these two places. At *A* find the error and rate of the chronometer, and then transport it to *B*. At the latter station take a *time* observation with the same chronometer; the time at *B* being known, and that at *A* being deduced from the indication of the chronometer, the difference between these two elements is the difference of the longitude required.

In practice when a chronometer is carried over-land, [illegible] not be relied upon in furnishing a very accurate difference [illegible] longitude between two places, as its rate becomes liable to irreg[illegible] variations from the jolting attendant on its transport. But the unc[illegible]inty which arises from the employment of one chronometer may often [illegible] got rid of by the use of several, when the mean of all the resul[illegible] may be assumed as the true difference of longitude between the t[illegible]o stations of observation. For more detailed instructions and the rigor[illegible]s methods

of finding the *longitude* by portable chronometers, see Chauvenet's "Spherical and Practical Astronomy," Chap. VII, pp. 317 to 339.

The extension of the system of telegraph lines to and throughout India necessitates some reference to the method of determining longitude by the electric telegraph, and the following extract from Chauvenet's "Spherical and Practical Astronomy" explains how this may be done.

"It is evident that the clocks at two Stations, A & B, may be compared by means of signals "communicated through an electro-telegraphic wire which connects the stations. Suppose "at a time T by the clock at A, a signal is made, which is perceived at B at the time T' by "the clock at that Station.

"Let ΔT and $\Delta T'$ be the clock corrections on the times at these Stations respectively (*both* "being *solar* or *both sidereal*).

"Let x be the time required by the electric current to pass over the wire; then A being "the more easterly station, we have "the difference of longitude λ by the formula

$$\lambda = (T + \Delta T) - (T'\Delta T') + x = \lambda_1 + x$$

"Since x is unknown, we must endeavour to eliminate it. For this purpose, let a signal be "made at B at the clock time T', which is perceived at A at the clock time T''; then we have

$$\lambda = (T'' + \Delta T'') - (T' + \Delta T') - x = \lambda_2 - x$$

"In these formulæ λ_1 and λ_2 denote the approximate values of the difference of longitude, "found by signals east-west and west-east respectively, when the transmission time x is "disregarded; and the true value is

$$\lambda = \tfrac{1}{2}(\lambda_1 + \lambda_2).$$

"Such is the simple and obvious application of the telegraph to the determination of longi-"tudes; but the degree of accuracy of the result depends greatly—(more than at first "appears) upon the manner in which the signals are communicated and received.

"Suppose the observer at A taps upon a signal key (see Vol. II, "Chronograph" for "the details of the apparatus here alluded to) at an exact second by his clock, thereby "producing an audible click of the armature of the electro-magnet at B. The observer at "B may not only determine the nearest second by his clock when he hears this click, but "may also estimate the fraction of a second; and it would seem that we ought in this way "to be able to determine a longitude within one-tenth of a second. But, before even "degree of accuracy can be secured, we have yet to eliminate, or reduce to a minimum "following sources of error:—

1*st*—The personal error of the observer who gives the signal; 2*nd*—The personal error "of the observer who receives the signal and estimates the fraction of a second by the ear; "3*rd*—The small fraction of time required to complete the galvanic circuit after the finger "touches the signal key; 4*th*—The *armature time*, or the time required by the armature at the "Station where the signal is received, to move through the space in which it plays, and "to give the audible click; 5*th*—The errors of the supposed clock corrections, which involve "errors of observation, and errors in the right ascensions of the stars employed.

"For the means of contending successfully with these sources of error we are indebted to "our *Coast Survey* (American), which, under the superintendence of Professor Bache, not "only called into existence the Chronographic instruments, but has given us the most "efficient method of using them."

In exploring new countries, or in accompanying armies on a foreign expedition, the time necessary for making longitude observations cannot be spared; in such cases the difference of longitude between two

places may be determined by means of a route survey combined with azimuth observations in the following manner:

It ought to be premised that the object of such a survey is not so much to lay down the road, as to fix with accuracy the positions of distant places; with this view the stations selected along the route should be as few as possible, and *not less than one mile apart.* The line of the road may be followed whenever stations can be fixed thereon fulfilling these conditions. But as this is a circumstance which is not always obtainable in practice, the road sometimes deviating from a straight course, and passing through towns which obstruct a distant view in front, the trace of the route in such cases may be carried out of the direction of the road, so as to pass clear of the obstructing towns, which, if required, may be connected with the trace aforesaid by offsets, or by subsidiary routes executed with different or inferior instruments.

There ought to be at least three perambulators for executing the linear measurement, their errors being previously ascertained by rolling them over a distance fixed by a trigonometrical operation. Two perambulators would be insufficient, for in case of discrepant results occurring, they will remain unaccounted for, the perambulator which has gone wrong, being detectable only by the employment of a third. At the commencement of the survey the perambulators being set to dissimilar readings, they will read differently all the way, and thus prove an effective check on the erroneous reading and noting of the distances.

A 7-inch Theodolite will be the best instrument for making the necessary angular measurement.

The distances and angles of the route will require to be measured according to the method of the Ray Trace Survey. In addition to these measurements it will be necessary to take *latitude* and *azimuth observations* at the origin, and in the vicinities of large towns, which are about one degree or sixty miles asunder, and also at the terminus. With good instruments both the latitude and azimuth in each instance may be ascertained with sufficient accuracy in two or three days.

When all these observations are completed, the reduction of the route may be performed in the following manner:

Let A and B be two consecutive stations on the route where astronomical observations have been made. It is clear first that the direct distance from A to B may be deduced according to the Ray Trace Method; 2nd, that with this distance, and the observed latitude and azimuth at *A*, the latitude of *B*, the back azimuth of *A*, and the difference of longitude between *A* and *B* may be computed as shewn in Part IV,

Chapter V; and that lastly a similar deduction with reference to *A* may be made from the observed elements at *B*.

When these deductions are finished, it will be seen that *A* and *B* will each possess two latitudes, one derived from observation, and the other from computation; and that likewise there will be two computed differences of longitude between these stations. If these results are accordant, it may be taken as a proof of the accuracy of the work. But as an agreement of this kind will rarely occur in practice, the best mode of dealing with the discordant data, is to take in every instance the observed latitudes, and the mean between the two computed differences of longitude, as the true values of these elements.

The limits A and B of the route being fixed, the intermediate points may be adjusted according to the method explained at pp. 462—464.

In the Appendix will be found a list containing the latitudes and longitudes of most of the well-known fixed places, derived from the Great Trigonometrical and Topographical Surveys of India, which will afford the best information to the surveyor for initial data in the prosecution of any survey operations within the limits of the District specified. They have been arranged alphabetically according to Provinces and Districts, and the three Presidencies separately detailed. The extension of the Great Triangulation, now almost over the whole of India, offers great facilities to the surveyor in the present day, and gives fixed data for starting almost any operations.

THE END.

APPENDIX.

Appendix.

INSTRUCTIONS FOR TOPOGRAPHICAL SURVEYING.

By LIEUT.-COL. A. S. WAUGH, Bengal Engineers, F.R.S., F.R.G.S.,

HONORARY ASSOCIATE, GEOGRAPHICAL SOCIETY OF BERLIN,
SURVEYOR-GENERAL OF INDIA, AND SUPERINTENDENT OF THE GREAT TRIGONOMETRICAL SURVEY.*

[*For the use of the Survey Department of India.*]

Printed in 1853.

Proposed scope of these instructions.

1. In the Manual of Surveying for India ample instructions have been given for triangulation of the second order, and for detail surveying in general. It is unnecessary, therefore, to repeat here what has already been completely described; but adopting the rules laid down in the Manual as a basis, it is intended in these instructions to recapitulate, with as much force as practicable, the great leading principles, which must not be departed from in extensive surveys, and to develop the system of internal detail best suited to surveys purely topographical in character.

Objects of a Revenue Survey.

2. The peculiar province of a Revenue Survey being to define boundaries of estates or properties, it is manifest that the principal operations of such a survey must be directed conformably to those boundaries; which require to be ascertained, and marked out before survey operations can commence.

Revenue Survey operations with Topography.

3. When the size of estates to be measured is considerable, as in Bengal, where the circuits are extensive, the operations of the Revenue Survey may obviously be made the basis of topographical delineations, whereby the expense of a separate basis is saved, and the districts can afterwards be incorporated by means of the great triangulation as described in the Manual. But when the size of the properties measured is so inconsiderable, as in the case of the Bombay Revenue Survey, and when they are further not included within principal circuits, those measurements cannot be combined to any extent, without running the risk of accumulating large errors, and therefore they cannot be made a basis for topographical operations, like the Bengal Surveys, in which field measurements are strictly internal and subsidiary.

Definition of a Topographical Survey.

4. The term "Topographical Survey" implies the measurement and delineation of the natural features of a country and the works of man thereon, with the object of producing a complete and sufficiently accurate map. Being free from the trammels of boundaries of properties, the principal lines operations must conform to the features of the country and objects to be surveyed.

* Now Major-General Sir A. Scott Waugh, Kt., retired.

Orthodox basis for a special Topographical Survey.

5. The only safe basis for topographical operations is beyond all question or dispute a system of accurate triangulation, whereby undue accumulation of error is precluded in the extension of the work, and at the same time limits are set to the intrusion of the error in the internal details.

Brief description of the G. T. Survey of India.

6. The greater the extent of country to be surveyed, the greater will be the risk of accumulating error in the triangulation itself, and hence, on account of the immense extent of British India, arises the necessity for superior accuracy in the Great Trigonometrical operations.

Methodical mode of procedure, the most correct as well as the most economical.

7. With the object of reducing the accumulating tendency within narrow limits, the Great Trigonometrical operations are carried on in principal series, proceeding in a straight course from one measured base to another, thus adopting the shortest lines of connection. The lines to which the series conform are either Meridional or Longitudinal, or approximating to the boundaries of the empire. These principal series are now generally made double throughout, thus affording additional checks at every stage of progress. As their course is straight, and the size of triangles the greatest the country will admit of, without violating the principles of symmetry, it follows that the stations of observation are reduced to the minimum number practically attainable. The greatest care and attention can thus be bestowed (with all due regard to economy) on the few great stations on which accurate continuity depends, and those observations are always taken with instruments of the first order by experienced observers.

8. These principal series are further checked by measured bases and Azimuths of verification. The accuracy of their sides being thus proved, those lines become fit to verify the next class of operations, *viz.*, the subsidiary Meridional series by which the country is traversed (or intended to be traversed) at every degree of longitude apart.

9. Subservient to these great operations are the secondary and minor triangulations, by which places of major importance are fixed, and great rivers traced out.

Operations of extension are never to be based on secondary Triangles of intersection.

10. This brief sketch of the system of the Great Trigonometrical Survey of India, though at first sight it may appear foreign to the subject of this paper, is nevertheless essential, because those great operations afford the primary basis for Topographical Surveys, which must either conform to the great triangulation already executed, or be susceptible of easy incorporation with series hereafter to be carried on. It is indispensable also that the distinction should be fully understood between principal and secondary operations, the former being as rigorously accurate as human means can make them, while the latter being intended for limited purposes cannot with propriety, be made a basis for extended operations.

Commencement of a Topographical Survey.

11. In commencing a Topographical Survey of an Indian district or territorial division it will be generally found that some portion of it has either been traversed by one or more of the great series above described, or some of the great stations will be found sufficiently near to afford a convenient basis for triangulation of extension. These stations furnish at once to the

Initial elements.

Topographical Surveyor the four initial elements required for commencing a survey, *viz.*, 1st, a point of departure, the latitude and longitude of which are fixed; 2nd, a linear element or base of ascertained length; 3rd, an initial Azimuth or true direction of the meridian; and, 4thly, the height above the sea level. The numerical values of these elements will be supplied on application to the Superintendent, G. T. Survey.

Internal triangulation.

12. As the great stations, however, are too far apart for immediate use in internal operations of detail, the great triangles may conveniently be broken down into smaller ones according to Colonel Everest's ray trace

system described in the Manual.* By means, therefore, of ray trace triangulation, and secondary points depending on the sides thereof, a sufficient number of fixed stations may be established in the immediate vicinity of the Great Trigonometrical series, and such points of reference should be about three to five miles apart according to the nature and value of the ground to be surveyed.†

Operations of extension described.

13. But this method is only applicable to ground covered by the great triangulation, or contiguous thereto. For other portions of the district or territory to be surveyed, provision must be made for extending additional large triangulations according to circumstances, *viz.* :

14. New points may be selected on the flanks of the great triangulation, so as to form an additional number of large symmetrical triangles, and in this way a breadth of 15 to 30 miles of hilly country may be embraced, or about seven or eight miles of flat ground.

15. Such additional triangles must be executed with the same rigorous precaution as in the Trigonometrical Survey. All three angles should be observed with an instrument, not less (if procurable) than 12 inches diameter, which should be duly isolated, and the signals should be luminous.

Extension by net-work.

16. If the space to be triangulated be greater than can be embraced by one set of these flank triangles, it will be proper in a hilly district to extend operations as far as the limits required, by means of a net-work of the largest symmetrical triangles that can be selected. These will arrange themselves into a succession of hexagonal or other polygonal figures, and it is to be remarked that the care and attention which should be bestowed on this part of the work ought to be strictly proportional to the extent to which the additional triangulation may require to be carried, the main object being to exclude accumulated error in extending the work. Hence the number of times the observations should be repeated, the size of the instruments, and every other element of accuracy should be in proportion to the distance to be triangulated. Manual of Surveying, Part IV, Chapter on Trigonometrical Surveying, &c.

Extension by Series.

17. In a flat country, however, the method of net-work would be expensive and dilatory, as well as liable to accumulated error. In such, if the area to be triangulated is large, it will be proper to carry a boundary series of triangles with sides as large as practicable along the outline of the district and perganas, or such internal boundaries, as are intended to be delineated. Minor series of this class should emanate from a *principal* side of the Great Trigonometrical Survey, and re-enter on another principal side, the former serving the purpose of an initial base, while the latter fulfils the object of verification. One flank of such a series should also conform sufficiently near to the boundary, so that the latter may be susceptible of easy connection therewith, while the course of the series should be as direct as circumstances will admit, because accumulation of error depends *cæteris paribus* on the length of the series, and number of stations employed.

18. It is to be understood, that a minor series of this class must be conducted with the same rigorous precautions that have already been enjoined in the case of a net-work.

19. If the space included between the bounding minor series and a great triangulation exceeds 20 to 25 miles, it may be desirable to break it up into smaller spaces by means of branch minor series, emanating from a principal side of the great triangles, and closing on a side of the bounding series.

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* See Part IV, Chapter on Minor Triangulation, &c.

† In the Na[illegible]l Surveys of England, France, and Bavaria, the internal triangulation was carried to a greater [illegible] of minuteness than is here contemplated.

Internal triangulation.

20. Having thus covered the whole field of survey with a net-work of large triangles in the case of hilly country, or with connected series in the case of flat lands, it will remain to interpolate other stations by means of the ray trace system, aided by secondary triangles, whereby the whole country may be covered with fixed points three to five miles asunder according to circumstances.

How to proceed when the district has been traversed by more than one Series of the G. T. Survey.

21. It may happen in some instances that a district to be topographically surveyed may have been traversed by more than one series of the Great Trigonometrical Survey. In such cases, the interval between two series must be filled up, if the country be hilly, with a net-work of large triangles uniting symmetrically with the flank sides of both series; but if the country be flat, minor series should be run across the vacant space, from one Great Trigonometrical series to the other. The ray trace triangulation, before adverted to, will furnish appropriate bases for such minor series to emanate from, and close on.

Methodical arrangement of operations recapitulated.

1st Class triangles or operations of extension.

2nd and 3rd Class or internal operations.

Triangles depending on mere intersections liable to error.

Triangles of intersection cannot be permitted to enter into operations of extension.

22. From this description it will be apparent, that the principle necessary to be observed in triangulating a district is to divide the operations into three classes, *viz.*, the 1st class, consisting of large symmetrical triangles, of which all the angles are to be observed with peculiar care, as well as with the best means, and it is to be distinctly understood that the advantage aimed at by this class of triangles is the prevention of accumulated error in extending operations to a distance. The 2nd class of operations consists of ray trace triangles, by means of which the larger triangles may be symmetrically subdivided into smaller ones. This class of operations is essentially internal, and therefore not productive of accumulated error; nevertheless all three angles should be well measured. The 3rd or last class consists of secondary triangles, whereby conspicuous existing objects or new stations may be fixed by intersections from the stations belonging to the superior classes of work. In fixing a secondary point by intersection, mistakes are liable to be committed, both in recognizing the object under different aspects, as well as ascertaining its name, more especially when the distance is great. Proper precautions must, therefore, be observed to insure identification in both those respects, and when practicable the same point should be intersected from more than two stations, whereby its position will become verified by common sides. If all due care be taken, these points will be sufficiently well fixed for topographical purposes, but they cannot be permitted to enter into any continued series or system of triangulation, of which the main object is accurate extension.

Computation of net-work.

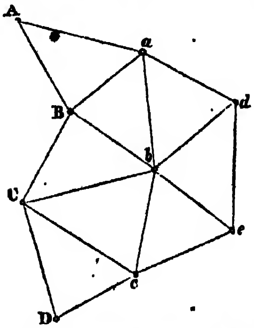
23. In all cases of net-work or triangles which combine into polygonal figures, the computations will not give consistent results, unless all equations of condition appertaining to the figures are previously satisfied according to Colonel Everest's method, described in his work, page 121, or Professor Galloway's method, *vide* Royal Astrl. Society's Memoirs, Vol. XV. The calculations for this purpose are, however, so complex and laborious as to be beyond the means and competence of topographical parties. It will suffice, therefore, for this class of operations to disperse triangular error by distributing one-third of its amount to each angle of the triangle, after which the latter may be computed as plain triangles, and the arithmetical means of common sides* should be taken for continuing the triangulation. If the observations have been

* When several independent values of the same quantity agree very nearly, it is [illegible]icient to take the mean of the Logs. of those values to represent the Log. of the mean of the natu[illegible] number answering thereto, but if the differences between the Logs. affect more than the 7th place, the m[illegible] natural numbers should be used, and its Log. taken out independently.

carefully made, the discrepancies in the values of such common sides ought to be extremely small, and therefore of no great importance.

Order of computation.

24. Some system, however, must be maintained in the order of computation, otherwise the mean results will vary according to the order in which the computations proceed. The principle to be observed is this; the values given by the Great Trigonometrical Survey are to be taken as fixed quantities, and those sides which are deduced immediately therefrom are considered of next importance, while those which are deduced by the same number of steps from the Great Trigonometrical values, are reckoned of equal weights. Thus supposing in the diagram in the margin that *A*, *B*, *C*, *D*, are stations on the flank of a Great Trigonometrical series, the values of those sides are to be taken as unalterable. Let *a*, *b*, *c*, *d*, *e* be stations of an extending net-work. Then the sides *Aa* and *Ba* will be obtained by computing the triangle *ABa*. Similarly, *Bb* and *Cb*, will be derived from triangle *BCb*. But the value of *ab* will differ, according as *Ba* or *Bb* be made the base for computing triangle *Bab*. The values of *Ba* and *Bb* are, however, of equal weight, being each derived from the basis by one step of computation. Hence *ab* will have two values of equal weight, the mean whereof should be taken for computing triangle *abd*. Similarly there will be two values of *bc*, and so on generally for all sides of these triangles.



Spheroidal nature of the earth's surface to be taken into account.

25. Any large portion of the earth's surface, such as a district or province, cannot however, be treated as a plain surface. The spheroidal excess of the large triangles will have been dispersed by applying one-third of the triangular error to each angle, which is strictly conformable to Legendre's rule; but with reference to the extension of the triangles over a spheroidal surface, together with the change in Azimuth, or inclination of Meridians that takes place, this will be duly provided for by computing the Latitudes, Longitudes and reverse Azimuths, according to the methods explained in Part IV of the Manual, Chapter on the Computation of Latitudes and Longitudes of Trigonometrical Stations.

Minute discrepancies in the common values of calculated position.

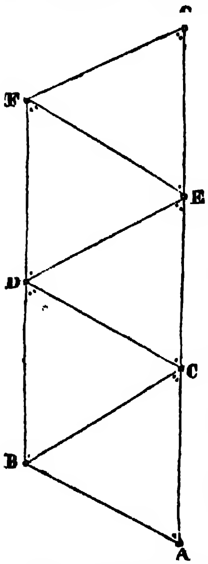
26. In prosecuting these latter computations, it will be found that the results derived from different sides will disagree by small quantities in the 2nd and 3rd place of decimals of a second. These discrepancies will be occasioned by the equations of condition not having been previously satisfied. The triangular correction being insufficient in complex figures, and the mean sides not corresponding with the angular elements with mathematical precision, the figures become more or less dislocated. There is no remedy for this inconsistency, but to satisfy all the mathematical equations of condition, by corresponding corrections, as has already been remarked. If, however, the work has been executed with all due care and with good instruments, the discrepancies in Latitude, Longitude, and Azimuth ought to be very minute, and barely appreciable.*. To enable the Topographical Surveyor to form a proper estimate of the character of his work, discriminating between discrepancies due

* Another [illegible] for such discrepancies, particularly in Azimuth, is the omission of spherical excess in computing s[illegible]y triangulation. The angles used in deducing Azimuths should be spheroidal. To obtain these, one-third the spherical excess requires to be added to each angle of a plane triangle. This should not be omitted by a careful computer, even in the case of secondary triangulation, when the sides exceed eight miles.

to want of refinement, and those errors which may arise from mistakes, it is to be remarked that 1″ of a great circle of the earth is very nearly 100 feet, and consequently 1 foot is nearly 0″·01 of Latitude or Longitude in India. The latter quantity would be an error totally inadmissible in great operations, but may be exceeded in subsidiary work, if the common sides differ more than two feet.

Linear discrepancy in verifying a Series, how treated.

27. It has been recommended to adopt minor series in flat countries in preference to net-work. Such minor series emanating from a side of fixed length, and closing on another of the same character, may be expected to exhibit a discrepancy of greater or less amount at the line of junction. Suppose δL to be the Logarithmic difference on comparing the last computed side, and n to be the number of triangles in the series, then on the hypothesis of a gradual and equal rate of generation of error $\frac{\delta L}{n}$ would be a Log. correction applicable to each side of continuation successively, and by applying such corrections to each triangle, the discrepancy at the line of junction would disappear; but the sides of the triangles, after being thus altered, would not agree with the angles for computation, and therefore this simple process would not prove satisfactory. To produce consistency between the angles and corrected sides, we may proceed in this manner. In any triangle ABC, appertaining to a series, if AB be the known side, and BC the next side of continuation for the series, then $BC =$ Log. AB + Log. sin A — Log. sin C; but if it be required that Log. BC should become Log. $BC + x$, then this new value will be equal to the expression Log. AB + (Log. sin $A + \frac{1}{2}x$)—(Log. sin $C - \frac{1}{2}x$). Hence if we take out the Log. difference due to 1″ for each of these two angles in every triangle of the series, and call the sum of these Log. difference S, then $\frac{\delta L}{S}$ will be the angular correction in seconds due to each of the two angles of the triangles, which enter into the computation for continuation.



28. If the cumulative correction required at the side of junction be positive, then the angular correction will also be positive to all angles opposite the side of continuation in advance (which angles are marked with a single dot in the diagram), and negative to those angles which may be termed the apices, being opposite to the known sides used as bases of calculation. These apical angles are marked with two dots in the diagram. The 3rd angle in every triangle, or that opposite the flank side, will not need alteration. After correcting the angles in the foregoing manner, and recomputing the triangles (or correcting the sides in proportion to the angular corrections), the discrepancy at the line of junction will be found to have disappeared, provided the calculations are carried to an additional figure of Logs. beyond the usual number of places.*

29. In this way consistency may be produced in the results of a minor series of importance; but it is not in general a matter of rigorous necessity, because the numerical

* Angular corrections of this kind ought to be very minute, and far within the probable errors of observation, otherwise the work is radically bad, and no system of treatment short of actual revision will do any good. *Vide* Manual, Part III, Chapter XVII on "the connection between the Great Trigonometrical and Revenue Surveys," on the subject of limit of error. In 1st class minor triangulation the error should be less than half a foot per mile, and in secondary operations based on the former or inferior triangulation, one foot per mile or 1-5280th part may be reckoned about the limit.

discrepancies likely to occur in calculating Latitudes, Longitudes, and reversed Azimuths appertaining to well-executed operations, will usually be so minute as to admit of being considered unimportant for topography.

Remarks on the formulæ for computing terrestrial Latitude, Longitude, and reverse Azimuths.

30. It is to be understood that our formulæ for computing Latitude, Longitude, and reversed Azimuth are approximate, being in fact a series of terms not regularly converging. Of these formulæ, the two first terms only are given in Part IV of the Manual, Chapter on the Computation of Latitudes, Longitudes and Azimuths of Trigonometrical Stations, the other terms being insensible for short distances. In the principal operations of the Great Trigonometrical Survey, however, the computation is always carried to the 3rd and 4th parts,* and it may be remarked, that in distances of 30 to 40 miles, the 3rd part may amount to half a tenth of a second or thereabouts in Latitude or Longitude, and sometimes nearly as much in Azimuth.

Method of plotting triangulation.

31. The Trigonometrical basis of a Topographical Survey having been laid out in the manner which has been here described, and the requisite computations having been effected, the next business is to plot the position of stations (by means of co-ordinates of Latitude and Longitude) on a skeleton chart, whereon the geographical lines have been previously correctly projected according to the rules given in Part III of the Manual, Chapter XVI on "the Method of describing the graticule of Maps."

Verification of the plot.

32. The protraction by co-ordinates should then be verified by distances, *i.e.*, by the length of sides of triangles, and, lastly, a comparison should be instituted with the angular readings or bearings in the field-books as a check against errors of direction. A further test of the most satisfactory character will be obtained, when the skeleton chart is mounted on the plane table, and the principal stations are visited by the detail Surveyor, who will thus have an opportunity of verifying the accuracy of the plot in a few minutes.

Intersected objects to be specifically described on the chart.

33. The precise part of those objects which have been fixed by intersection, such as temples, buildings, &c., should be briefly, but significantly, specified on the chart, to prevent mistakes in identifying the exact points fixed.

Topographical operations, various methods of procedure.

34. The next question for consideration is the best method of filling in topographical details. There are three methods of procedure available: 1st, the method of measuring up the minor triangles on the principles of the Ordnance Survey, as described by Captain Frome in his work; 2nd, by traversing from trigonometrical point to point, and taking offsets and intersections; 3rd, by means of the plane table.

Mechanical operations.

35. The two first methods being purely mechanical in principle, and susceptible of easy check, may readily be carried out by native agency, if it can be procured sufficiently cheap. However, as all surveying comes ultimately to sketching in the ground, provision must be made for performing this part of the duty artistically, unless indeed the contour-system be adopted, by which means the character and configuration of the ground can be accurately delineated mechanically, without the aid of any artistical talent whatever. A contoured Trigonometrical Survey, however, would be extremely costly as well as slow in progress,† for

* Special Tables for facilitating the Great Trigonometrical Survey computations have been printed, (Auxiliary Tables, 1868), and are procurable on application to the Surveyor-General.

† Contouring costs about Rs. 40 per mile, and prolongs the time occupied in completing the maps nearly three fold. The last Parliamentary Report on the Ordnance Survey of Scotland has pronounced the contouring system unadvisable, on the evidence of the most celebrated Civil and Military Engineers of the day.

which reasons that system of internal survey is hardly applicable to the circumstance of India in the present day, and certainly totally inapplicable to the Native States, or to the mountainous and jungly tracts belonging to the Government of India. These two classes of country form the only field for surveys purely topographical, all the rich districts coming specially within the scope of the Revenue Survey system.

Plane Table surveys, or the method of the Bavarian cadastre and Madras surveys.

36. An inexpensive and rapidly conducted but perfectly complete survey is what is urgently required in India, and these objects can most effectually be attained by plane table surveys, based on the trigonometrical operations before described. This method, however, requires able and practised draftsmen.

Cautions in using the Table.

37. The principle of the plane table is that of trigonometrical intersection, and demands the same caution as has been already enjoined in the case of secondary triangles.* Accumulation of error cannot take place in such a survey, as limits have already been set to it by the fixed points trigonometrically established. The accuracy of the internal detail within these limits will, on the other hand, depend on the shortness of the distance from which the ground is sketched up, as well as on the care with which points are intersected from the Trigonometrical stations, and the necessary offsets measured up and plotted on the board.

Trigonometrical marks and flag stations.

38. All Trigonometrical stations must first be marked in some conspicuous manner, such as is described in the Manual, Part IV, Chapter on Trigonometrical Surveying, &c., and flags or other marks should be planted at those additional points where the table is required to be set up. Such plane table positions being fixed *à priori* from the Trigonometrical stations, render the Surveyor independent of the magnetic needle, in the use of which much caution is requisite on account of hourly variations and liability to disturbing attractions. It is reckoned that the compass may be trusted for distances on the board, less than the needle's length, but not for distances exceeding that length, for obvious reasons. To set up a table at an unfixed station, the needle and two visible fixed stations are the least required, but a careful Surveyor would not be satisfied with less than the needle and three visible stations, which proves the work. To enable this method to be practised on such occasions as it is applicable to, it is necessary at the outset, on commencing a new board, to set it up at a great station, and after rectifying and proving its position by observations to the circumjacent great stations, the magnetic compass should be placed on some convenient part of the board. The table being fixed and the needle adjusted to the north mark and standing quite steady, the Surveyor will proceed to draw the outline of the box on the board and to make marks corresponding with those on the box, which may be either circular with four marks or square or oblong. The needle should be strongly magnetized and play quite free in the box. Its indications should also be tested by comparison with a standard needle occasionally, or with the true meridian, and if found to differ, and particularly if it hangs back, giving different indications according as the box is turned from the left or right, then the point of suspension will be found to be bent, and should be rectified. The other method of interpolating stations is by observations to three known points, a problem equally unsatisfactory in plane tabling as in trigonometry, and which should never be resorted to in accurate surveys. A practical solution of this problem is given in Appendix marked A, but more as a matter of curiosity than utility. All young hands are fond of interpolating stations, but it is an inadmissible principle except for very subsidiary details. The accuracy of the work depends on drawing true rays from the Trigonometrical stations, and by that means fixing a number of plane table stations. This rule cannot be too strongly insisted on.

* See Memorandum following, on the use of the *Plane Table* for topographical purposes, by Captain D. G. Robinson, R.E., 1st Assistant, Surveyor-General's Department, in charge No. 1 Topographical Survey.

39. A hilly country offers the fairest field for the practice of plane table surveys, and the more rugged the surface the greater will be the relative advantages and facilities this system possesses over the methods of actual measurement. On the other hand, in flat lands the plane table works at a disadvantage, while the traverse system is facilitated. Consequently in such tracts, the relative economy of the two systems does not offer so great a contrast as in the former. In closely wooded or jungly tracts, all kinds of survey operations are prosecuted at a disadvantage, but in such localities, the commanding points must be previously cleared for trigonometrical operations, which facilitate the use of the table.

Advantageous conditions.

40. On a scale of one mile to an inch a district can be completely surveyed by means of the plane table, at a cost of 6 to 8 rupees per square mile, including the expense of minor triangulations.* On this scale, all those objects should be delineated which are essential in a map for Political and Military purposes, as well as for those of local improvement.† The scale of ½ inch per mile is to be resorted to only in very dense jungly countries containing a scanty population and little cultivation, with a dangerous climate, rendering it desirable to accelerate progress.

Scale of survey will be ordered by the Surveyor-General.

41. On the scale of one mile per inch a practised draftsman can execute about five square miles per diem,‡ while on the half-inch scale 16 square miles may be accomplished, in each case supposing the detail to be minutely drawn, and nothing omitted which the scale admits of being represented. Thus on the one-inch scale, any natural feature, such as a ravine or watercourse less than one-eighth of a mile in length, cannot well be shown; and if the country be intricate and full of detail, objects less than one-fourth of a mile cannot easily be represented without creating confusion and destroying the unity of the general effect. On the half-inch scale, the limits to the power of representation appear to be double the above quantities, between which they will vary according to the nature of the ground. All these rates refer to ground of ordinary character. In easy country, open and early level, or hills of simple outline, the work will be done cheaper and faster; but in ravines and intricate ground or hills of irregular formation and difficult to travel over, the cost may be enhanced considerably. It must be recollected, however, that such tracts are generally of little value and do not demand so much precision and minuteness of detail as other valuable lands. In such wild tracts it is sufficient that the character of the ground should be correctly represented and its prominent features distinctly shown, in which case watercourses of one-fourth of a mile would hardly attract attention. If the greatest precision and minuteness aimed at, none but skilful draftsmen can be expected to survey five square miles a day independent of the triangulation which must be previously plotted on the board. The rate of Rs. 6 per square mile, over all, is derived from the Hydrabad Survey, but will vary in proportion to the salaries and the number of subordinate surveyors employed under one Superintendent. Allowance must also be given for the determination of elevations which, if numerous,

Rate of progress in proportion to scale, and not including field measurements.

* The cost of the topographical surveys of the present time (1873) is Rs. 22 per square mile. The system of survey has been greatly improved, and rigorous accuracy is enforced by checks applied in the field.

† This opinion, which I have held for years, is perfectly conformable to the last decision of Parliament on the Ordnance Survey; which decision was based on the evidence of eminent Civil and Military Engineers whose opinions were taken. The distinction, however, between a map and a plan must not be lost sight of. The former embraces a wide extent of country and on scales suitable for such areas, information can only be generalised. Hence maps cannot supply the place of plans, nor supersede the necessity of special survey for special purposes.

‡ In the present day (1873), with the degree of accuracy that is now required and enforced, it is not found possible to complete more than two to three square miles daily of good reliable work in fairly open country; in difficult ground not more than two square miles can be accomplished even by the most expert Surveyors.

and extended to all obligatory points for roads, draining and canals as hereafter explained, will considerably enhance the cost.

42. Whether the details be taken up in the first instance on the principle of the plane table, or by traverse operation carefully plotted, the work will have to be mounted on the boards for examination in the field and to enable the configuration of the ground to be sketched up in a characteristic manner.

Delineation of the configuration of the ground.

43. In delineating a corrugated surface, the rule to be attended to is, first, to draw in carefully the arterial drainage system or watercourses, constituting the outfall of the country, and next the water-sheds or ridges of hill must be traced.* Having thus outlined the highest and lowests levels of the ground, the subordinate features can be put in with great precision, but as these require to be generalized in proportion to the scale, an operation depending entirely on judgment and *coup d'œil*, a considerable degree of artistic talent and practice is necessary to ensure success.† The outlines of table-land should be well defined, and ranges of hills pourtrayed with fidelity, carefully representing the water-sheds or *divortia aquorum*, the spurs, peaks, depressions or saddles, isthmuses or connecting links of separate ranges and other ramifications. The depressed points and isthmuses are particularly valuable as being the sites of ordinary passes or points which new roads should conform to. These are the chief heads to be attended to, as regards physical relief; but the water system or drainage and depressed features, such as ravines, are also of the greatest importance. Every bend or angle of a stream or streamlet should be accurately fixed; whereby a true representation of its course will be given, and not a mere similitude or rough likeness depending on vermicular contortions, with which common surveys are disfigured, but which are totally unlike nature. The general outlines of ground as defined by ridges, watercourses, and feet of hills must absolutely be fixed by actual survey, otherwise the work would be mere reconnoisance and no two Surveyors working independently would produce the same results. This is the distinction between survey and reconnoisance, the delineation of the Artist being in the first case rendered accurate by the precision with which the outlines are fixed, whereas in reconnoitering, more is trusted to the eye. The rest is a matter of shading, and there are three modes of execution, *viz.*, 1st, by brush-shading or general washes, varying in intensity with the steepness of the slopes; 2nd, brush-shading relieved by contour touches, sketched on the ground; 3rd, vertical hatching similar to engraving.‡ The last method, however, depends on the 2nd, because contour lines must be drawn to regulate the

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* Since the above was written, it has been pointed out to me that the same rules very nearly [illegible] given in the masterly paper on Field Sketching in the Aide Memoire to the Military Sciences, Vol. II, page 523, published by Weale, *viz.*:

On whatever scale the subjects of study may be, the master lines of ground are,—

1st,—The main or summit ridges of the mountain or hill.

2nd,—The watercourses.

3rd,—The coast or horizontal contour lines.

The subordinate lines are those more or less oblique contour lines, defining the minor features, and generally called "feature lines."

The Surveyor is recommended to refer to this admirable paper for further information and illustration of the method of delineating and shading the natural forms of ground.

† Care should be taken to avoid the opposite error of suppressing the minor features entirely; because their omission produces a monotonous effect, nothing helps to work out the main features so characteristically as a clear representation of minor features within due limits.

‡ The mode now adopted, to suit the process of reproduction by photo-zincography, is that of hatching, horizontal lines, or eye-contours, being preferred to vertical lines (1873). Specimens of Horizontal Hill Drawing (Major Petley's Series) and several plates illustrating the Horizontal System of Hill Drawing as now adopted (1872) on all the Imperial Surveys of India, suitable both for maps on ordinary scales and large scale plans, can be obtained from the Office of the Surveyor-General of India.

vertical strokes, each row of which should conform to a contour, while the direction of each stroke is to indicate with precision the direction of the declivity, otherwise the configuration will not be truly expressed. The object of all shading is to depress the furrows and elevate the ridges or intumescent forms. This can be done with best effect by the 1st method for small scale manuscript maps, such as ¼-inch scale geographical maps, *et infra:* by the 2nd method for one-inch scale maps, and by the 3rd method for larger scale plans, for which a combination of all three modes is generally necessary to work out the effect, and this also is sometimes necessary for the one-inch scale, when the relief requires to be picked out. The hypothesis of vertical illumination is here supposed to regulate the shading, because it is the only method by which relative commands and intensity of slope can be expressed on the usual scales of maps. For plans on large scales, the artistic effect produced by oblique light is an advantage, which is unattainable on the small scales of maps.

Large rivers to be triangulated by minor series with stations on both banks.

44. Large rivers are fit objects for triangulation by minor series, by which means their general directions can be accurately traced. After which their special features can be drawn characteristically, *viz.*, their margins or banks, breadth of water and sands in the dry season; ferries and fords (with the depth of water thereon to be recorded), and the outline of floods.

Statistics.

45. The one-inch scale admits of villages, towns, and cities being represented in a general way according to their relative sizes, with the principal streets or roads by which they are intersected, and outlines of fortifications. The number of houses should be estimated and recorded in the register. To prevent omissions, lists of villages should be obtained in the first instance from the civil authorities, and a copy of these lists should afterwards be returned to the same authorities with the estimated number of houses for examination. Trial should then be made of the number of inhabitants per house in various parts of the district, by which means data will be forthcoming for a tolerable approximate estimate of the population of the district, *vide* Chapter on General Statistics, &c., of the Manual. Whatever be the scale of the vey, a register is to be kept of the latitude and longitude of every village taken by admeasurement from the map, as soon after the field plot has been made as practicable. By means of these numerical data, the map can always be projected on any scale, and errors arising from shrinking or other alterations in the paper of the original map, will be guarded against. The register also admits of corrections in orthography being introduced into the fair copies, which cannot be done on the original maps without injury to the drawing. Names also can thus be restored if obliterated and omissions be checked. This register will also exhibit the number of houses, and the height above sea-level where it has been determined.* By this means the importance of the village or town can be duly estimated and the style of printing made to conform thereto.

46. On a scale of one inch per mile the general figure and extent of cultivation and waste and forest tracts can be delineated with more or less precision according to the size of the masses in which these distinctive features occur, distinguishing especially irrigated rice lands which generally display the contours of the ground. The areas of these several portions can be estimated from map measurement, and thus will be obtained further elements for the statistical information required. Historical enquiries should also be prosecuted and information collected, regarding the staple agricultural productions, geological formations, mines, and mineral resources, and all other items of interest suitable to a statistical memoir† to accompany the map. In prosecuting such enquiries application should be

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* Printed forms for these Registers are now used (1873), and these can be obtained on Indent from the Surveyor General's Office.

† For heads of this Memoir, *vide* Chapter on General Statistics, &c., Manual of Surveying for India, and also Memorandum (I) Appendix.

made to the Civil authorities to supply information, or verify the researches of the Survey Department.

Orthography.

47. Great care is requisite in the orthography of native names, regarding which the rules of Chapter, on the Orthography of Native Names, of the Manual are to be scrupulously adhered to. In verifying the names of places, assistance may also be expected from the Civil authorities, and it is to be considered one of the main objects of a Surveyor's duty that his map should fully satisfy the wants of those authorities.

48. The means of communication, whether by roads or minor tracks, are important, both for Civil and Military purposes, and should be carefully inserted in the map. This can generally be done with facility in a hilly country, as the fixed marks will be visible in sufficient number along the road, so that the latter may be drawn in at once by plane table operations along the line of communication to be surveyed. In flat countries, or where the view is circumscribed, it may be necessary to resort to measurements and plotting, but should any case occur where the fixed points of reference are far apart, the traverse system must be resorted to, and the road should be plotted from computed co-ordinates.

Order of procedure. Topography not to be commenced until sufficient triangulation has been executed, plotted, and projected on the table.

49. The supposition has been hitherto made, that before taking up any part of the details, the whole district should be triangulated, the computations effected, and the fixed points carefully projected. This principle is undoubtedly correct, but in practice it may be desirable to aim at a division of labor and saving of time by setting the plane tables to work as soon as a sufficient portion of the district has been triangulated, &c., and the points projected on the tables. It is, however, clearly to be understood that no detail should be taken in hand until a sufficient number of fixed points have been satisfactorily established, and the whole area to be surveyed should be methodically apportioned into a convenient number of plane table sections, in such wise that they may readily be incorporated without overlap or hiatus. In arranging this distribution, the whole area of a board should not be considered available, but a margin of two or three inches or more ought to be left all round for external fixed points, which are required for working upon near the edges of a section—*vide* Memorandum G.

Principal territorial boundaries, where any doubts exist, to be drawn on a separate chart and referred to the Civil power for orders.

50. It will be indispensable to lay down the boundaries of the principal territorial subdivisions on the map; and to prevent mistakes in defining their limits, every care and precaution ought to be taken to ascertain them with all due precision, timely application being duly made to the proper authorities on this subject.

Elevation and depression of ground.

51. The relative heights of hills and depths of valleys are facts of importance coming within the scope of a Topographical Survey. These vertical ordinates may be determined geometrically or barometrically, or by a combination of both systems. The barometer is more especially useful for determining the level of low spots from which the principal Trigonometrical stations happen to be invisible. In using this instrument, however, in combination with other operations, the relative differences of heights are to be considered the quantities sought, so that all the results may be referrible to the original Trigonometrical station. The height above the sea-level of all points coming under any of the following heads are especially to be determined for the purpose of illustrating the physical relief of the country, *viz.* :—

1st,—The peaks and highest points of ranges.

2nd,—All obligatory points required for Engineering works, such as roads, drainage and irrigation, *viz.*, the highest points or necks of valleys—the lowest depressions or passes in ranges; the junctions of rivers and debouchements of rivers from ranges; the height of inundation-level at moderate intervals of about three miles apart.

3rd,—Principal towns or places of note.

52. The methods of determining heights geometrically has been fully explained in the Manual, and it is only necessary in this place to add, that in using those instruments of the minor class which have two vertical arcs with a pair of verniers regulated by a level, the observation will be facilitated as well as improved in accuracy by applying a scale to the level. The angular value of the divisions of this scale can be ascertained by experiments with a good instrument, and thus corrections may be applied to the vertical angles for those small deviations in the indications of the level which it is difficult to eliminate practically, but very easy to correct theoretically. The principles of procedure in such cases are very fully explained in the annexed Memoranda marked B and C, but it is utterly impracticable to impart by means of written instructions a thorough knowledge of the use of instruments and more especially of the vertical apparatus, the principles of which vary in different instruments, and are always more or less complex. For these reasons the Surveyor should learn these parts of his duty practically at head quarters or with the nearest party of the G. T. Survey. *Vide* additional Memorandum marked H.

Level correction.

To teach the use of instruments by written instructions, impracticable.

Periodical returns made to the Surveyor-General.

53. To enable a sufficient check to be exercised during the progress of the work, the following returns are required to be periodically forwarded to the Surveyor-General of India, *viz.*: —

1st,—A Monthly Progress Report exhibiting the distribution and employment of each Surveyor and the quantity of work executed, whether in field or in office.

2nd,—An annual narrative of operations to be sent in on the conclusion of each field season in tabular form.

3rd,—An annual Tabular Return* of Progress and Expenses, exhibiting the cost of survey per square mile, to accompany narrative report due at the close of each recess season.

4th,—An annual Return of Instruments and Government Property, specifying the depôt from which received, and date of receipt, as well as their state of efficiency.

The officer in charge responsible for the efficiency of instruments and equipments.

54. It is to be distinctly understood that the officer in charge of a Survey is responsible for maintaining the instrumental equipment in efficient order. All requisite repairs are to be made during the recess, and those instruments which require repairs beyond the competence of the Surveyor to execute, should be sent to the Mathematical Instrument Maker's department or to the nearest magazine, as circumstances may render advisable, or should be returned into store and replaced by efficient instruments. Timely application must be made to the Surveyor-General for orders on this subject.

Mapping.

55. The mapping must on no account be allowed to fall into arrears. The following plans are therefore to be brought up season by season:—

1st,—A skeleton chart of triangulation on the one-inch scale (scale of survey), for the use of the Surveyor's office.

2nd,—A reduced copy of the above on ¼-inch scale (4 miles to the inch), for the Surveyor-General.†

3rd,—Plane table sections on the one-inch scale (scale of survey), for the Surveyor-General, *vide* Memorandum G.

* Statement A.

† Now (1872) required on ¼-inch scale in complete degrees, with numerical data inserted.

4th,—Fair compilation map on the one-inch scale (scale of survey), *vide* Memorandum G, for the Surveyor-General. These are now submitted (1872) in standard sheets of a uniform size, *viz.*, 30 minutes of Longitude by 15 minutes of Latitude.

5th,—Reduced compilation map, scale ¼ inch to the mile, Memorandum G, for the Surveyor-General.*

6th,—Skeleton progress map, on a scale of 8 or 16 miles per inch, *vide* Memorandum G, to accompany Narrative Report. Printed Index maps are now (1872) supplied to each party, on which each season's progress is represented by tints of color.

56. Maps, plans, &c., should not be mounted on cloth, because it renders the tracing of copies for lithographic or other purposes a matter of difficulty.

Official records.

57. The following office books should be kept up and not suffered to fall into arrears :—

1st,—Letter-Book for correspondence with the Surveyor-General, his deputy and other professional Officers.

2nd,—File of Letters received from above parties.

3rd,—Miscellaneous Letter-Book.

4th,—File of Miscellaneous Letters received.

5th,—Pay Abstracts and Acquittance Roll-Book.

6th,—Contingent Bill-Book.

7th,—The usual field books and computations which are to be kept in duplicate, one copy to be forwarded to the Surveyor-General.

8th,—File Departmental Orders and Circulars, Vol. 1st, professional subjects ; Vol. 2nd, non-professional subjects, *viz*, accounts, &c.

58. All these office records are to be legibly written in a neat style and kept clean. The duplicate field-books and computations are to be rigorously compared, and must on no account be suffered to fall into arrears, nor be daubed with blots or written illegibly. Neat clean writing, and well-formed figures, methodically arranged, are in fact essential ele[illegible] of accuracy in elaborate computations, and as this is entirely a matter of habit[illegible] must [illegible] insisted on from the beginning. Observations and memoranda ar[illegible] to be recorded in pencil, or on loose scraps of paper, but entered at once in ink [illegible] the proper books kept for the purpose.

Range of duty expecte[illegible] the head of the par[illegible]

59. Although operations of extension may be considered the peculiar province of the head of the party, he [illegible] also take a leading share in every part [illegible] the [illegible]ies, never exp[illegible] more [illegible] than [illegible] do himself, and showing, by personal example, how their several duties are to be performed.

Sanatory cautions.

60. The Officer in charge should be careful of the health of his followers and himself, for the due preservation of which in jungly tracts separate medical instructions have been issued.

The true principles on which celerity of progress depends.

61. It is in vain to expect rapidity of progress from hurrying on the work, the effect of which is only to produce confusion and mistakes. Celerity will naturally follow that facility and skill which are acquired by long practice, combined with an undeviating system of order and method.

Disputes to be avoided.

62. The Officer in charge must also be careful to prevent disputes between his people and the inhabitants, with whom he should endeavour to establish friendly relations, and acquire the confidence and support of the local authorities He should be chary of the expenditure of public money,

* No ¼-inch compilation map is now required (1872) from Executives.

Fig. 3

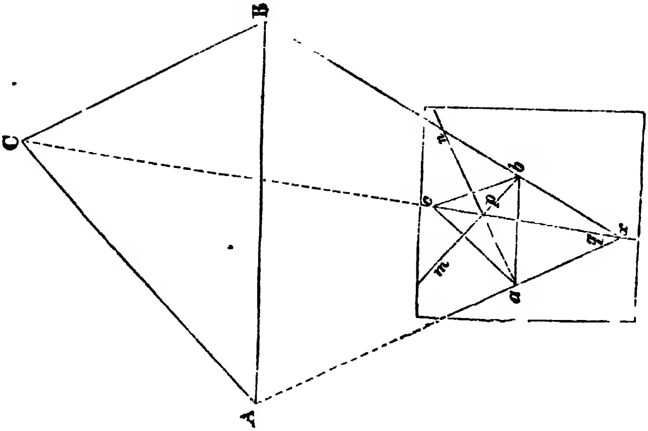


Fig. 2.

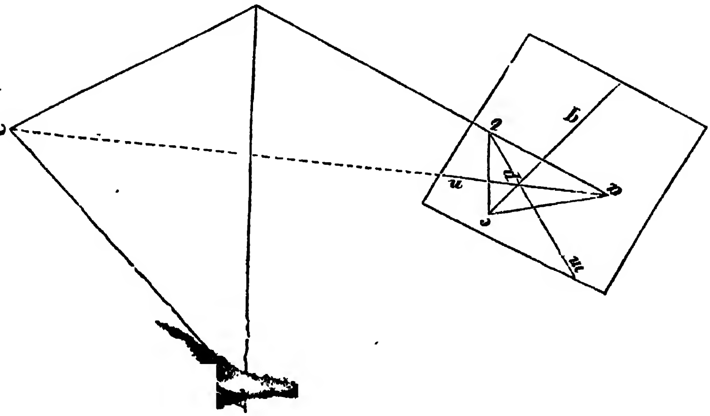
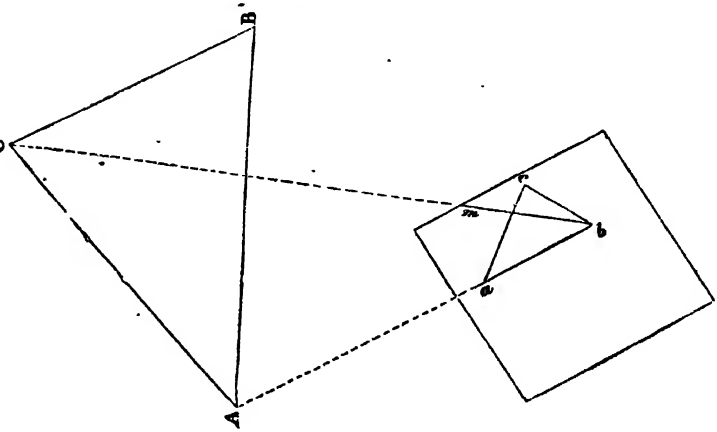


Fig. 1.



and by precept as well as example should encourage his followers in the manly discharge of their public duties, the acquirement of a high professional reputation, and a character for respectability and cheerfulness of spirit.

Doubtful points to be referred for orders.

63. Instructions, however elaborate and minute, cannot supersede the necessity of judgment and discretion on the part of the Executive Officer, who is strictly responsible for the success of the work. If doubts or difficulties arise, immediate reference is to be made to the Surveyor-General.

Final professional report.

64. On the conclusion of the Survey, a professional report on the operations and construction of the map is to be drawn up and submitted. The memorandum, marked I. in the Appendix, contains the heads of the subjects proper to be discussed, in this final professional report.

A. S. WAUGH, *Lieut.-Colonel,*
Surveyor-General of India.

MEMORANDA REFERRED TO IN THE ABOVE INSTRUCTIONS FOR TOPOGRAPHICAL SURVEYING.

A. Problem for fixing a station on the plane table, by means of intersections to three known points.

B. Rules for determining the value of the division of a level scale.

C. Rules for correcting vertical angles for level errors.

D. Description of a new Theodolite Stand and Plane Table in use with the G. T. Survey.

E. Blank forms of returns.

F. Estimate for a Topographical Survey party.

G. Memorandum on Mapping, illustrated with a specimen of a Plane Table section.

Additional remarks on vertical angles, for determining terrestrial heights.

final professional report.

'ble the Court of Directors on Statistics.

A.

unknown po[illegible] by [illegible] of three points *ADC* whose positions are laid down on the plane table and represented by *abc* respectively.

Vide Fig. 1. of diagram opposite.

Fix a pin in the point *b* on the plane table, and placing the ruler against it and the point *a*, with the object and sight towards *a*, turn the table about, until the point *A* is intersected, then clamping the table in this position, turn the ruler and intersect the point *C*, with the edge of the ruler still against the pin at *b*, and draw the line *bm*;—now remove the pin to the point *a*, and unclamp the table,—place the ruler against the pin at *a*, and the point *b*, and turn about the table until the point B is intersected (*vide* fig. 2); clamp the table again, and having intersected the point *C* as before, draw the line *a n* through the intersection *p* of the line *a n* and *b m;* draw the line *c p q* passing through the point *c*, and placing the edge of the ruler against this line, unclamp the table once more, and turn it about until the point *c* is intersected (*vide* fig. 3); now clamp the table, and it will be in position, and the unknown point *x* will be situated on the line *c p q;* to find this point it is merely necessary to intersect either of the points as *A*, and draw the line *A a x*, and the accuracy of the operation is tested by intersecting the other point B and drawing the line B *b x* which should intersect the line *A a x*, on the line *c p q*, thus giving the position of *x* on this line.

.The demonstration of this problem is evident to those acquainted with the same problem in plane trigonometry; it only remains to be remarked, that when the point c with regard to the point x is situated on the other side of the line A B, or below it, the lines a n and b m will intersect on the opposite side of the line a b to that on which c is; and if the point x be situated within the triangle A B C, these lines (a n and b m) will diverge instead of converge, in which case they must be prolonged on the opposite direction until they intersect for the point p.

N.B.—The accuracy of the result depends on the length of the line c p.

Remark.—The problem for fixing an unknown station by observations thereat to three known ones, is only applicable to reconnoissance, and totally inadmissible for accurate surveying. The rules for trigonometrical operations prescribe symmetry and the measurement of every angle at accessible stations. Plane tabling is perfectly similar, and the points at which the table is to be set up should first have rays drawn to them from the trigonometrical stations. Interpolated stations are inadmissible except for very subsidiary details, and should, for such purposes only, be fixed by the needle and three known points at least.

B.

G. T. SURVEY.

Rules for the determination of the value of a level scale.

The value of the divisions of the scale of a level may be ascertained by affixing the level to the frame of the vertical circle (or making it ride parallel to the telescope) and then taking readings of the microscopes in two positions of the bubble, whence comparing the number of divisions of the level scale run over by the bubble, with the corresponding angular motion of the vertical circle, as measured by the microscope, the value of one division of the level scale will be obtained by simple proportion as shown in the following example:—

Experiments made at Kalianpoor, January 1840, to determine the value of the divisions [illegible] axis level appertaining to the circle Troughton.

Temperature.	Microscope Readings. D.	Difference.	E.	Difference.	Mean difference.	Level Readings. [illegible] end	Difference.	O. end	Difference.	Mean difference.	Computed value of one division of level scale.
°	° ′ ″	″	′ ″	″	″						″
70·7	7 25 47·0		25 41·0			85·6		48·4			
	7 26 20·5	33·5	26 14·1	33·1	33·30	50·9	34·7	83·0	34·6	34·65	0·9610
	7 26 12·1	8·4	26 6·0	8·1	8·25	59·9	9·0	73·9	9·1	9·05	0·9116
	7 25 62·1	10·0	25 56·2	9·8	9·90	70·1	10·2	63·8	10·1	10·15	0·9754
	7 25 52·2	9·9	25 45·0	11·2	10·55	81·0	10·9	53·1	10·7	10·80	0·9769
	7 25 44·2	8·0	25 37·3	7·7	7·85	89·9	8·9	44·3	8·8	8·85	0·8870
	7 26 11·1	26·9	26 4·9	27·6	27·25	61·2	28·7	73·0	28·7	28·70	0·9495
											5·6614

Mean value of one division of the level scale ... ... 0·9486

The above form exhibits only a few of the experiments necessary for determining the value of a level. For the azimuth level of an astronomical circle, not less than 50 to a 100 observations should be taken; for the azimuth level of the Great Theodolite about 80

observations will suffice; for transit axis levels about 15 to 20 observations, and for inferior instruments about the same number. These observations should not be taken at one time, but under as great a range of temperature and circumstances as practicable; some in the hot, some in the cold weather, morning, noon, and evening, and with various lengths of run, taking special care to avoid allowing the bubble to approach too near the end of the scale on the one hand and on the other avoiding small runs. The run to be measured should not in any case be much less than 10 divisions, because the uncertainty of reading arising from indefinitude in the bubble, partial expansions and other sources of error, produces a proportionally greater effect on a small run. Supposing, for example, in a fine level, that the uncertainty in two readings, *i. e.*, on a run, may be 2-10ths of a division (which is a moderate assumption), then the uncertainty in 10 divisions will be 1-50th part of the whole quantity. In small common levels, the uncertainty will be much greater, perhaps as much as half a division. A good level should be sensible in every sense of the term, *viz.*, both sensitive and steady. This happens when its internal surface has been ground to an arc of a perfect circle, but as the instrument-makers have no certain means of grinding to a perfectly circular figure, the requisite conditions are in a great measure a matter of chance, and a good level a matter of selection.

In circles, equal parts of the circumference subtend equal angles, which is not the case with elliptical or other geometrical curves, or with an irregular curve. If the internal surface of a level were perfectly cylindrical, the bubble would remain at any part when the cylinder was level, and would run up to one end or the other on the slightest inclination, so that the quantity of angular deviation could not be measured. If the internal surface were convex, the bubble would run on to one end, and there would be no indication of the true level, or of the amount of deviation therefrom. If the surface be concave, but of elliptical or any other curvature excepting circular, equal parts will not subtend equal angles, but the indications would otherwise be steady. Lastly, if the surface is irregular, the bubble will be liable to fits and starts and irregular indications. A good 10 or 12 inch ground-level generally runs 30″ to 40″ in the inch although they sometimes run as fine as 20″ to 25″, but the latter are generally unsteady. Common short levels run from 40″ to 100″ in the inch, [illegible] being not an unusual value. Supposing the internal surface to be a true circular arc the [illegible] that circle for a level having 30″ in an inch will be 573 feet, because $\frac{\text{cosec } 1''}{12\times30} = \frac{206264\cdot8}{12\times30} =$ [illegible]. For 40″ to the inch, the radius is 430 feet, and for 80″, 214 feet.

As the grinding does not ex[illegible] to the extremities of the glass, and no readings are ever taken near the ends, it is necessary, when measuring the runs, to be careful not to make the bubble approach too near the ends, as [illegible] been already remarked.

If the runs of a level vary under di[illegible] temper[illegible] the [illegible]l surface is most like[illegible] or some other geometric curve. A mean value, derived fro[illegible] experiment under various temperatures, should in such cases be used, provided the variations are minute; but if they are large, it may be necessary to use a different value for different temperatures, as shown in the annexed memo. of experiments :—

Memo. on the Level Experiments at Kalianpoor, 1839-40.

The run of the level is apparently very much affected by temperature as will be seen from the following statement:—

Temperature	74°·8	... ...	value of 1 division	0″·7871
Ditto	72 ·4	... ...	ditto	0 ·7594
Ditto	70 ·5	... ...	ditto	0 ·7478
Ditto	66 ·45	... ...	ditto	0 ·7317
Ditto	60 ·27	... ...	ditto	0 ·6858
Mean ...	68 ·9		Mean ...	0 ·7424

This indicates a correction of 0″·00698 nearly, for the value of the level for every degree of the thermometer, on which assumption the computed values for the other temperatures, are as below:—

Temperature.	Computed values of one division of the level.	Difference from observation.
74°·8	0·7836	− 0·0035
72 ·4	0·7688	+ 0·0094
70 ·5	0·7535	+ 0·0057
66 ·45	0·7392	+ 0·0075
60 ·27	0·6821	− 0·0037

In applying a level to a vertical circle for the purpose of measuring the angular value of the scale, the best plan is to fix on the bars or on the telescope, two Ys of wax, in which the level can be made to sit firm, taking care to secure it from accident by tying it on. The level must be accurately cross-levelled, so that it may occupy the same position under trial as in actual use. If there be no cross-level attached, one may be temporarily fixed on with wax, before dismantling the level, but if means are not available for this purpose, then, before taking the level off for trial, mark with pen and ink on th[illegible]lass the outline of the bub[illegible] This will give the means of approximately cross-levelling, and however [illegible] the device may be, it is infinitely preferable to trusting to chance.

Besides this mode of determining the value of a [illegible] scale, there is another method applicable to levels of azimuthal instruments w[illegible]h may be called an examination in *situ*, as it does not require the level to be det[illegible] fixed on to a vertical circle. The method is as follows:

Bring the object or eye end of the telescope plumb over a foot screw. Turn the whole instrument till the telescope is directed on the referring mark at a time of day when the altitude is steady.* Now level the instrument. It is clear that if the screw under the telescope end be raised and depressed, the amount of dislevelment so occasioned may be measured both by the level and by the apparent change of altitude in the mark, consequently the deviations of the former may thus be compared with the divisions of the vertical circle. This method can only be practised at one period of the day, but as that period is most favorable for vertical angles, it is not unsuitable for obtaining a value for correcting those observations.

N.B.—Levels being very sensitive thermometers, care must be taken not to influence them by breathing, or too near an approach of the body.

* About 3½ hours p. m.

Experiments taken at Masuri Observatory to determine the value in seconds of the Divisions of the Vertical Axis Level attached to Simms' 24-Inch Theodolite, No. 2, by Captain Thomas Renny-Tailyour, Astronomical Assistant, Great Trigonometrical Survey.

Temperature and date.	Micrometer Readings. A.	Diff.	B.	Diff.	Mean Diff.	Level Readings. L. end	Diff.	O. end	Diff.	Mean Diff.	Computed value of one division of Level Scale.
1853*						d.	d.	d	d.	d.	
71°2	85°56′25″·2		56′44″·8			90·5		40·2			″
	57 15 ·2	50″·0	57 34 ·4	49″·6	49″·80	40·6	49·9	90·4	50·2	50·05	0·9950
31st Aug.	56 35 ·4	39 ·8	56 54 ·6	39 ·8	39 ·80	80·0	39·4	51·0	39·4	39·40	1·0102
	57 3 ·3	27 ·9	57 23 ·3	28 ·7	28 ·30	51·7	28·3	78·5	27·5	27·90	1·0143
	56 43 ·8	19 ·5	56 63 ·2	20 ·1	19 ·80	70·0	18·3	60·8	17·7	18·00	1·1000
71°2	56 54 ·7	10 ·9	56 73 ·9	10 ·7	10 ·80	60·7	9·3	70·2	9·4	9·35	1·1551
70 1	57 17 ·3		57 38 ·6			87·4		43·2			
	58 8 ·1	45 ·8	58 23 ·8	45 ·2	45 ·50	43·5	43·9	87·6	44·4	44·15	1·0306
	57 30 ·3	32 ·8	57 51 ·7	32 ·1	32 ·45	77·0	33·5	53·8	33·8	33·65	0·9643
	57 52 ·9	22 ·6	57 73 ·7	22 ·0	22 ·30	53·4	23·6	77·6	23·8	23·70	0·9409
	57 38 ·8	14 ·1	57 59 ·2	14 ·5	14 ·30	67·8	14·4	62·8	14·8	14·60	0·9795
70 1	56 29 ·7		56 49 ·8			85·0		47·2			
71 2	57 8 ·3	38 ·6	57 26 ·7	36 ·9	37 ·75	47·3	37·7	81·9	37·7	37·70	1·0013
1st Sep.	56 39 ·0	29 ·3	56 58 ·4	28 ·3	28 ·80	75·0	27·7	56·4	28·5	28·10	1·0249
	56 57 ·8	18 ·8	56 77 ·0	18 ·6	18 ·70	55·8	19·2	75·6	19·2	19·20	0·9740
	56 47 ·0	10 ·8	56 65 ·4	11 ·6	11 ·20	66·0	10·2	64·8	10·8	10·50	1·0667
71°2	56 31 ·8		56 51 ·2			82·3		48·5			
71°2	57 4 ·8	33 ·0	57 23 ·4	32 ·2	32 ·70	49·1	33·2	81·9	33·4	33·30	0·9820
	56 40 ·3	24 ·5	[illegible]0 ·1	23 ·3	23 ·90	72·7	23·6	57·9	24·0	23 80	1·0042
71 2	56 56 ·0	15 ·7	[illegible] 74 ·2	14 ·1	14 ·90	58·8	13·9	72·2	14·3	14·10	1·0567

By 10 previous me[illegible] at Temperature 46°·8	1″·1639
By 10 ditto ditto 47 ·2	1·1743
By 10 ditto [illegible] ·8	1·1527
By 10 ditto ditto 53 ·6	1·1563
By 10 ditto ditto 55 ·3	1·1205
By 16 measures at Temperature 70°·9 as shown above	1·0187
General Mean of 66 measures at above Temperatures ...	1·1311

* Remarks.—The azimuth level was examined *in situ* by bringing the eye end of the telescope immediately over one of the foot screws, and at the same time intersecting the wires of a 30-inch Transit used as a Collimator.

The runs of the transit axis level of the same instrument were determined by fixing it on the vertical circle. The mean of 50 observations at temperatures 47°4 to 56°5 gave 0·71859 for the value of one division of the Level Scale.

C.

RULES FOR CORRECTING VERTICAL ANGLES FOR LEVEL ERROR.

Extract from Circular Order, Department G. T. Survey, Surveyor-General's Field Office, Dehra Doon, 1*st September*, 1849.

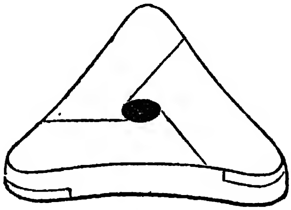
2nd. The reading of each end of the level is to be registered in two columns marked "object end" and "eye end." The object end readings are to be marked + and the eye end readings marked —. The Algebraical sum of the whole will be divided by the number of level readings, each end being considered an independent observation. The quotient will be the level error in terms of the level scale, which, multiplied by the angular value of the divisions of the scale, will give the angular correction with its proper sign, to be added algebraically to altitudes, and subtracted from depressions.

D.

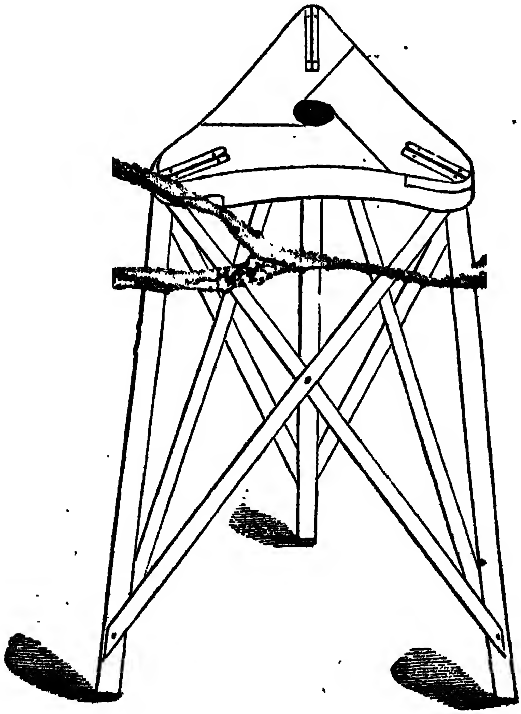
DESCRIPTION OF A NEW THEODOLITE STAND,

IN USE WITH THE G. T. SURVEY.

Plan showing the head of a trestle composed of three solid pieces notched down on each other. Diameter 8 inches, thickness 2¼ inches.

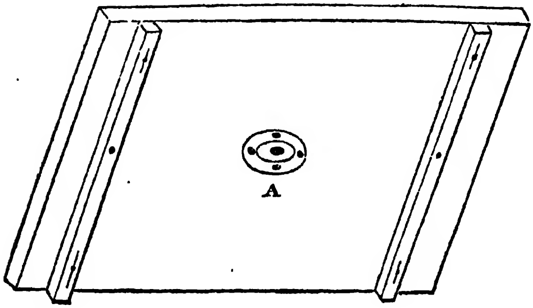


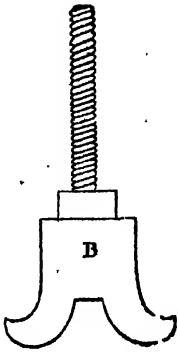
Plan of trestle head showing the brass grooves suited to Theodolites of 5 inches to 12 inches.
The screws all brass, with nuts of brass.

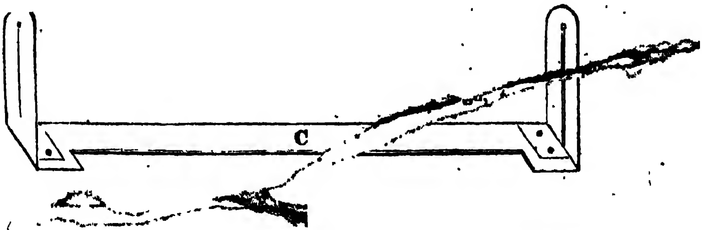


DESCRIPTION OF A NEW PLANE TABLE,

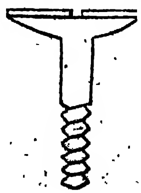
IN USE WITH THE G. T. SURVEY.







A shows the under part of a Plane Table, with the brass Socket screw in its centre countersunk and fixed by 4 screws. The board is made of planks of well-seasoned toon or deal wood, one inch thick. To prevent warping, edge bars are attached across the grain. These edge bars are to be fixed firmly by one screw in the middle. There is also one screw at each end, passing through a long hole, so as not to impede expansion and contraction. These latter screws should have broad heads, and should not be screwed too tight, and the shoulders should be slightly bevelled, or turned off, so as to offer the least possible resistance, thus.. ....



Moreover a piece of brass or tin should be placed between the shoulders of the screw and wood, to prevent countersinking, which would prevent the expansion and contraction of the wood. After being made up and well aired and seasoned, the surface of the board should be planed true and smooth.

B is the screw for fixing the Table and the Stand.

C is the Sight-rule for Plane Table.

GENERAL REMARK.—Iron is inadmissible on account of the Compass.

D.

(Example 1st.)

North East Longitudinal Series.

Vertical Angles taken at CHANDIPAHAR HILL STATION with Lieut.-Colonel Waugh's 24-inch Theodolite, No. 1.

Object.	Face.	Time of Observation.	Micrometer Readings. G.	Micrometer Readings. H.	Level Readings. Object End.	Level Readings. Eye End.	Mean Vertical Angles. One face.	Mean Vertical Angles. Both faces.	Mean Vertical Angles. General Mean and level corrn.	Height of Object.	Barometer Reading.	Thermometer. Attached.	Thermometer. In the air. Dry.	Thermometer. In the air. Wet.
					+	—								
		h. m.			Afternoon Vertical Angles, 19th November 1850.									
					d	d								
Roorki Station Heliotrope	L	2 40	D0° 43′ 25″.5	D0° 43′ 43″.6	82 .0	65.0	D0° 43′ 34″.55	D0° 43′ 37″.98	D0° 43′ 37″.89	0·6 feet above the station mark.				
Ditto	R	44	D0 43 54 .8	D0 43 28 .0	74 .5	72.0	D0 43 41 .40		Corn.=−5.69					
Ditto	R	50	D0 43 55 .0	D0 43 28 .8	73 .0	72.6	D0 43 41 .90	D0 43 37 .80	D0 43 32 .20					
Ditto	L	3 0	D0 43 27 .0	D0 43 40 .4	83 .4	64.2	D0 43 33 .70				In s. 27.926	66°.0	69°.8	58°.3

Remarks.—Value of one division of level scale = 1″.64.
The station mark is on the highest part of the roof of the College, 27 feet above the ground.
Height of eye = 5.4 feet.

Calculation of level error $(+\overset{d}{312.9} - \overset{d}{273.8}) = +\overset{d}{39.1}$ hence $+\dfrac{\overset{d}{39.1} \times 1''.164}{8} = +5''.69$ subtractive from depressions.

(EXAMPLE 2ND.)

NORTH EAST LONGITUDINAL SERIES.

Vertical Angles taken at GHOON[illegible]TI HILL STATION with Lieut.-Colonel Waugh's 24-inch Theodolite, No. 1.

Object.	Face.	Time of Observation.	Micrometer Readings. G.	Micrometer Readings. H.	Level Readings. Object End.	Level Readings. Eye End.	Mean Vertical Angles. One face.	Mean Vertical Angles. Both faces.	Mean Vertical Angles. General Mean and level corrn.	Height of Object.	Barometer Reading.	Thermometer. Attached.	Thermometer. In the air. Dry.	Thermometer. In the air. Wet.
					+	—								
Afternoon Vertical Angles, 20th December 1850.														
		h. m.			d	d								
Saonchalia H. S. Heliotrope	R	2 0	E0° 23′ 30″.7	E0° 23′ 14″.3	95.5	102.0	E0° 23′ 22″.50	E0° 23′ 28″.20	E0° 23′ 28″.20	1 .67 feet.				
Ditto	L	3	E0 23 22 .3	E0 23 44 .7	98·5	98.5	E0 23 33 .50		Corn. =−2.62					
Ditto	L	8	E0 23 23 .2	E0 23 45 .0	9 ·0	98.0	E0 23 34 .10	E0 23 28. 40	E0 23 25 .58					
Ditto	R	10	E0 23 30 .6	E0 23 14 .8	92.9	104.5	E0 23 22 .70				In s. 23.347	55°.2	56°.4	49°.0

Remarks.—Height of eye = 5.40 feet.

Calculation of level error $(+\overset{d}{385.0} - \overset{d}{403.0}) = -\overset{d}{18.0}$ hence $-\dfrac{\overset{d}{18.0}\times\overset{''}{1.164}}{8} = -2''.62$ additive to elevations.

Observed by Th[illegible] Renny Tailyo[illegible], *Captain, Astronomical Assistant, G. T. Survey.*

E.

REPORT PROGRESS of No. ______ *Topographical Party* ______ *Survey, for the Month of* ______ *187* .

Name and Designation.	On what duty employed during the past month.	Progress and present state of the work.	On what duty proposed to be employed during the ensuing month.	REMARKS.
Deputy Superintendent.				*N.B.*—Full particulars, briefly described, as to the *progress made* in mapping, computations, plane tabling, triangulating, &c., should be given in this report.
Assistant Superintendent.				
Surveyors.				
Assistant Surveyors.				
Sub-Surveyors.				

Date

Signature.

ANNUAL RETURN of Instruments, &c., the Property of Government in use with No.______ Topographical Survey ending 1st September, 187 .

Names and description of Instruments, &c.	No. or Quantity.	Maker's Name.	Whence received.	Date of receipt.	Remarks.
(In exact Alphabetical order.)					

Date Signature.

FORM No.

MONTHLY STATEMENT of Expenses of No. Topographical Survey, for the Month of 187 .

Name of Treasury where Bills for the Month were Cashed.	No.	Designation and Name.	Military Pay and Allowances.	Staff or Civil Pay.	Total of each Class or Denomination.	Total Monthly Expenditure.	Total Expenditure from 1st April to	REMARKS.
		(1) EXECUTIVE OFFICERS.						*Note.*—Dates of going on leave and return to duty to be entered in this column.
		Deputy Superintendent of Survey, grade ...						
		Assistant ditto, do. ...						
		Total						
		(2) SURVEYORS AND ASSISTANT SURVEYORS—FIELD ESTABLISHMENT.						
		Surveyors, 1st grade						
		Do. 2nd do.						
		Do. 3rd do.						
		Do. 4th do.						
		Assistant Surveyors, 1st do.						
		Do. do. 2nd do.						
		Do. do. 3rd do.						
		Do. do. 4th do.						
		Total						
		(3) SUB-SURVEYORS—FIELD ESTABLISHMENT.						
		Sub-Surveyors, 1st grade						
		Do. 2nd do.						
		Do. 3rd do.						

Statement of Expenses.—(Continued.)

(3) SUB-SURVEYORS—FIELD ESTABLISHMENT.—(*Contd.*)															
Sub-Surveyors, grade															
Do. do.															
Apothecary															
Hospital Assistant															
Tindal No. Rs. ; Duffadar No. Rs. ;															
Flagmen No. Rs. ; Carriers No. Rs. ;															
Hurkaras No. Rs. ; Jemadar Rs. ;															
Naibs Rs. ; and Burkundazes Rs. ...															
Total															
(4) OFFICE ESTABLISHMENT.															
Writer															
Total															
(5) CONTINGENCIES.															
Purchase of Stores															
Do. of Tents, &c.															
Do. of Medical Stores and Medicines ...															
Miscellaneous: Office Rent; Carriage of Public Property, Rs.; Guides, Rs.; Coolies, &c., Rs.; Jungle or line clearing, Rs.; Petty Office contingencies, &c., Rs.; Camels at Rs. each per month, Rs.; Compensation or Batta to Native Establishment for dearness of Provisions.; Pay and charges for Police Guards															
Total															

(6) TRAVELLING EXPENSES.	
Field daily allowance and mileage to Executive Officers by road or rail	
Ditto ditto to Field and Native Establishment by road or rail	
Travelling allowance of Office Establishment by road or rail	
Travelling or mileage charge for rail or road expenses for going to and from Recess Quarters, for newly appointed men in joining their posts; for extra or excess travelling bills under para. xiii of Financial Resolution, No. 704, dated 22nd February 1866, &c.	
Total	
(7) LOCAL ALLOWANCES.	
Local allowance to Executive Officers	
Do. to Field, Native, and Office Establishments	
Total	
(8) POSTAGE CHARGES.	
Purchase of Service Stamps	
Total	
(9) CATTLE OR ELEPHANTS.	
Purchase of Cattle or Elephants	
Feed and keep of do.	
Total	
Aggregate Total ...	

	Rs. A. P.
Amount of Budget Estimate ...	
Deduct Expenditure from 1st April 187 to end of	
Balance ...	

N.B.—The last column should shew the total of the nine different heads of expenditure, instead of shewing the total expenditure of each item arranged under the nine heads.

Office of No. Topographical Party
Survey
187 .

No.
SUBMITTED
TO THE SURVEYOR-GENERAL OF INDIA,
CALCUTTA.

Superintendent, Grade,
In charge No. Topographical Party,
Survey.

STATE

N.B.—To accompany Narrative Report due on the 1st October of every year.

Return of Professional Field and Office Work of No. Party
30th September 18 *exhibiting*

Number of detached parties.		Amount and Nature of Triangulation completed, Instrument used and number of Zeros for Observations.					Area Triangulated in square miles, and cost.		Area of Triangulation in advance of Topographical Details.	Average Error Of Triangles.	
On Triangulation.	On Details.	1st class Triangles, and ∠s observed on Zeros.	Secondary Triangles, and ∠s observed on Zeros.	2nd class Triangles, and ∠s observed on Zeros.	Minor Secondary Triangles, and ∠s observed on Zeros.	Heights.	Area and Total cost of Δ n.	Cost per Square Mile.		Triangular Error of 1st class Triangles.	Triangular Error of Secondary Triangles.

Date on which the Party took the field,	General Remarks.
Date of return to recess quarters.	Linear miles of check routes or traversing completed during the season.

N.B.—In filling up this Return the

OFFICE OF NO. PARTY TOPOGRAPHICAL SURVEY
Dated the 1st October 18 .

MENT A.

Topographical Survey for Season 187 , *namely, from 1st October* 18 *to the*
Area, Cost, Rate of Survey, &c.

of Triangulation.				Quantity of Topographical Details completed by each Member of the Party and total area.	Average number of Plane Table Fixings per square mile in each person's work.	Minimum number of Plane Table Fixings in each person's work.	Total cost of final Survey, including season's Triangulation, and cost per square mile.	Names of Districts, Talooks, Mehals, &c., through which the season's operations have passed.	Computations, Angle Books, &c.		Fair and rough Maps and Charts.		Remarks.
Of sides.													
1st class per mile.	Secondary per mile.	2nd class Secondary per mile.	Minor Secondary per mile.						Completed.	In arrears.	Completed.	In arrears.	
Cities or towns, cantonments, civil stations, forts, &c., surveyed and mapped on large scales.									Number of Stations at which observations were taken.	Number of Points laid down by the Season's Triangulation.			Total area of Triangulation completed since 18 the season the survey commenced Do. of Topographical details* Do. Do.

utmost attention must be paid to accuracy.

Deputy Supdt. in charge, No. *Party,*
Topographical Survey.

No.......... TOPOGRAPHICAL PARTY...SURVEY.

REPORT PROGRESS for the Field Season of 18 .

Names and Dates of Appointment.	On what duty employed during the last year.	Progress and present state of the work.	On what duty proposed to be employed during the ensuing year.	REMARKS.
Deputy Superintendent.				
Assistant ditto.				*N.B.*—An Index Chart, illustrating the area triangulated and the area topographically surveyed, is to accompany this Report.
Surveyors.				
Assistant Surveyors.				Full particulars should be entered in this Report of the work performed by each member of the Party.
Sub-Surveyors.				

Date.

Deputy Supdt. in charge, No. Party,
Topographical Survey.

F.

ESTIMATE FOR A TOPOGRAPHICAL SURVEY PARTY.

Corrected, 1873.

STATIONERY.

Foolscap Paper	2 to 3 reams.
Country ditto	4 to 5 „
Quills	300 to 400.
Steel Pens for writing	4 gross.
Gillott's Mapping Pens or Crow Quills (steel)	3 „
Blotting Paper	20 quires.
Atlas Drawing ditto	12 sheets.
Double Elephant ditto	24 „
India Rubber	20 pieces.
Pencils, Drawing, H. H., 4 doz.; H., 3 doz.; H. B., 2 doz.; F., 2 doz.; B., 1 doz.	12 dozens.
Antiquarian Drawing Paper	6 sheets.
Tracing Linen 10 yards, or Tracing Paper	20 „
Wax Cloth	4 pieces.

Books—2 Letter Books, 3 quires Foolscap.
1 Pay Book, „ „ (forms bound.)
1 Contingent Bill Book „ (ditto.)
1 ditto for each Assistant „
4 Memorandum Books for each Assistant, or 50 for the whole Party.
3 Books for filing letters received.
Portfolios, 2 or 3, for Maps. Tin Cases or Tubes for rolls of Maps, &c., 4 to 6.
Lithographed Forms, Angle Books, &c., to be indented for as required.
Files for Departmental Orders and Circulars, &c.

INSTRUMENTS.

TELESCOPES (Hand).—Ten or twelve; Binoculars, six to eight.

THEODOLITES, with Stands or Trestles.—One large Theodolite for operations of extension, *viz.*, a 14-inch, 12-inch, or 10-inch, according to the distance to be triangulated. One 7-inch or 5-inch for each Surveyor employed on internal operations.

SIGNALS.—Twenty to twenty-four Heliotropes, large and small, for operations of extension; eight Flags with bamboo staves, &c., for each Surveyor employed. In hilly countries poles and brushes can be used extensively, and flags will not be much required.

PLANE TABLES, with Stands and Sight Rulers.—One for each Surveyor employed, including the officer in charge, and six spare ones; one level, two sets of Staves.

MAGNETIC COMPASSES.—Two box needles for each board; two Prismatic Compasses with stands for the Party.

MAGNETS.—One pair, for remagnetizing needles.

MEASURING APPARATUS.—One iron chain to be used as a standard of comparison; one 6-foot standard iron bar; one measuring chain for each Surveyor, or one or more perambulators in lieu of chain, according to the nature of the Survey.

POCKET OR BOX SEXTANTS.—Two Sextants 10 or 12-inch.

BAROMETERS.—Two, previously compared with the standard in the Surveyor-General's Office, for determining the altitudes of places inaccessible to trigonometrical levelling.

Office Instruments.—Four boxes of mathematical instruments, with proportional compasses and four small boxes; one box of colors,* &c., to each Assistant; four Gunter's scales; four beam compasses, large and small; two straight-edge flat rulers; two T squares; one parallel ruler for each Plane Table Surveyor; two planimeters or area computing scales divided for 1 inch = 1 mile, for obtaining areas; spare dividers bowpens, drawing pens, &c., as necessary.

Books.—Manual of Surveying for India; Logarithms; 1 Bagay; 2 Shortredes, Sines, &c., and numbers; 2 Hutton; 1 Babbage Numbers; 1 Babbage Sines and Tangents or Callet's; Auxilliary Tables to facilitate the computations of the Survey Department, India, 4 copies; Index to Departmental Orders and Circulars, 2 copies; Revenue Survey Handbook.

STRENGTH AND COST OF A TOPOGRAPHICAL SURVEY PARTY, 1873.

Establishment.

	Annual Rs.	
1 Deputy Superintendent, 1 Assistant Superintendent, 1 Surveyor, 6 Assistant Surveyors	40,000	
5 Sub-Surveyors, 1 Writer, 1 Hospital Assistant ...	4,200	
1 Tindal, 1 Duffadar, 31 Flagmen, 35 Carriers, 1 Jemadar, 2 Naibs, 16 Burkandazes, 2 Hurkaras, Total 89 men	6,200†	
	50,400	Total cost of Establishment.

Contingent and Miscellaneous Charges.

Field Allowances, Purchase and Repair of Tents, Carriage of Government Property, Office Rent, Police Guards, Conveyance Charges by Rail and Dâk, &c., Postage, Feed and Keep of Elephants, Tools, &c., &c.	18,000	
Annual Cost, Total ...	68,400	For a Party of full strength.

Local allowances, under special circumstances, are also allowed to some Surveys at certain fixed percentage rates to cover the cost of excessive dearness of provisions, carriage, &c.

Prior to 1861, or before the introduction of the Budget System of Estimates and Expenditure, no fixed sum was allowed for the Topographical Survey Department, but during late years the total annual sum sanctioned is, in round numbers, Rs. 4,50,000, divided amongst seven Survey Parties.

The total annual cost of a Party, as shown above (Rs. 68,400), varies according to the rates of salary for different grades of Officers of the Senior Department and Subordinates composing it; the contingent and miscellaneous charges also alter from local causes, but Rs. 68,400 is a fair average for the present time.

* 1 cake Prussian Blue, 1 cake of Indigo, and 1 Cobalt,
1 cake Lake or Carmine, and 1 cake Light Red,
1 cake Gamboge, and 1 cake Yellow Ochre, } with 3 pairs hair pencils.
1 cake Burnt Sienna, and 1 cake Burnt Umber,
1 cake Indian Ink, and 1 cake Sepia,

† During the recess (five months) the Native Establishment is greatly reduced by discharging all extra men and granting leave on half pay to others.

G.

1. The whole district to be surveyed should be apportioned out in sections to the Assistants by the head of the Party, who is responsible for the combination of the different parts.

2. On the 1-inch scale, the most convenient size for a plane table section is fifteen minutes of a degree, or about 17·2 inches in latitude by 17 to 14 inches in longitude according to the parallels. Such a section will require a board at least 22 inches square, so as to give room for external points as adverted to in para. 49; but boards of 26×30 inches would answer better, because room would be given for additional tiers of sub-sections to assist in protracting external points. It is to be understood that the lines defining sections are to be set out to correspond with the geographical degrees and quarter degrees, and they projected by doubling the tabular quantities in the new Geodetical Tables (See Tables end of Chap. XV, Part III) taking due care that the central meridian of each section intersects the parallels at right angles. *Vide* Example G′, Plate XIX.

3. The sections may, for convenience, be subdivided into sub-sections of 5′, and the Trigonometrical points will be projected by the use of appropriate scales.*

4. The section lines define the limits to be surveyed up to, so that when all the sections are placed side by side, they are intended to produce a complete map. When any portion of a district occupies a part only of a section, it will nevertheless require a full sectional sheet for its survey, however small the portion surveyed may be, so that every field-sheet will be of uniform size. The Assistants should work together in the first instance at their common boundaries to such extent as will ensure agreement on the lines separating their respective portions. To effect a general agreement and consistency of style, the head of the Party should be competent to direct and instruct his subordinates in every part of the work.

5. These sectional sheets are the field-books of the Survey, and must be preserved accordingly. They are therefore intended to be sent to the Surveyor-General, by whom they will be placed in a book or portfolio, duly indexed, previous to dispatch to the India House.

6. The meridians and parallels defining the sections are to have their geographical values carefully printed, whether they be degrees or quarter-degrees, for on this depends the due incorporation of the sheets without mistake. As a further precaution against confusion or omission, each sheet is to be endorsed on its back with the Nos. of the meridians and parallels by which it is bounded.

7. For the half-inch scale, the sections should be half a degree in latitude and longitude, and to them the other rules above given equally apply.

8. The names should always be printed to the right of the villages or towns to which they belong, and on a line of parallel, *i.e.*, due east and west; the names of rivers parallel to their courses; and the same as respects those of mountain ranges. With regard to

* One advantage of these sub-sections is as follows:—Paper is liable to expand and contract from Hygrometric causes. On account of the distortion so engendered, no map can be trusted for large spaces. Half a per cent. of alteration is not an unusual quantity in India. This will be nearly insensible in a space of 5′. Hence the map may always be re-projected from the numerical values of Trigonometrical data, after which the details of the 5′ spaces can be copied without accumulating errors.

the size of print applicable to these names, and to those of territorial divisions, modern or ancient, reference may be made to the Manual, Part III, Chapter XIV.

9. After the field sections have been fairly copied into the general compilation map on the same scale, they are to be carefully packed in double tin and a wooden case, and forwarded season by season to the Surveyor-General, with a copy of the register.

10. The compilation map is intended to incorporate the field sections into a district map, in which unity of style is particularly to be attended to. This compilation is to be forwarded to the Surveyor-General (carefully packed as above) after the receipt of the field sections has been acknowledged. This is in accordance with a general rule, not to entrust the original and duplicate of any work to the post at one time; thus the means of replacing a lost document will always remain in hand.

11. No specific rules seem necessary for the preparation of the fair compilation map. The projection of the Geographical lines on which it depends will be based on the Geodetical Tables, and care is requisite in proportion to its superior size, so that the projection may not accumulate error. The projection of the Trigonometrical stations must be carefully done by appropriate scales and duly verified by linear distances, after which the easiest way is to trace in the details of each section consecutively from the glass. Great care and precaution will be required in preserving the compilation map from injury and Hygrometric changes. When the size of the district requires that the 1-inch scale compilation should be got up in sheets,* then each sheet when finished is to be sent to the Surveyor-General.

12. The same rules apply precisely to the reduced quarter-inch scale map.

13. The skeleton map is to be a mere outline, showing the extent surveyed by each individual, distinguishing the same by a wash of color and the season of survey recorded thereon, which with the Geographic lines will serve to illustrate the Narrative Report, and show the progress achieved.

H.

VERTICAL OBSERVATIONS.

EXTRACT FROM INSTRUCTIONS FOR A TRIGONOMETRICAL SURVEY.

1. Every exertion should be made to enable you to observe verticals at minimum refraction, for those taken later are worthless—about half-past 3 P.M., or as soon as objects begin to steady for horizontal angles, they rise at the rate of 1″ per minute, or even more rapidly. Thus a few minutes difference of time will cause greater error than observing unsteady objects. As a general rule, it is better to observe verticals too early than too late, for even at noon the uncertainty in the mean of several intersections to an undefined dancing object, would not much exceed 2″, an error which at a later period of the day might be occasioned by about 2 minutes in the time of observation.

2. If your sides in the plains do not exceed 11 miles, your stations always on high ground, the towers sufficiently high, and due care taken to avoid intermediate obstacles such as can neither be removed nor surmounted, there will be no difficulty in getting verticals at minimum. The period of minimum refraction lasts a considerable time, probably from noon to the epoch of maximum temperature, which is generally reckoned to occur about 3 P.M. As soon as the thermometer begins to fall, objects begin to rise, and it is the evil effects of this uncertain change in altitude which it is desirable to avoid. When verticals are observed before 3 P.M. in the cold, and say half-past 3 P.M. in the hottest weather, identical times are of less importance because in several minutes there will be no change of

* These maps are now rendered (1874) in sheets of one uniform size, viz., 15 minutes of Latitude by 30 minutes of Longitude.

altitude, but still it is a good habit to observe reciprocal verticals at exactly similar times for if from circumstances, the observations should in the least degree overstep the limits of minimum, then perfect equality of time is an essential condition of success. To ensure this requisite identity of time in reciprocal observations, a well-regulated watch is necessary. In the plains time can be ascertained with sufficient exactness by observing sunrise and sunset (noting the same in the angle book,) the half interval between which will be apparent noon; or apparent noon can be estimated from sunrise or sunset alone by means of a table of the sun's rising and setting, such as is published in the Ben[illegible] In hilly countries this simple expedient cannot be practised for want of a natural horizon, but time can always be ascertained with sufficient exactitude by equal altitudes of the sun, taken with the small Theodolite. By any of these means, you can regulate the observations of reciprocal verticals, so that they may correspond exactly in regard to times after noon, and it is the time from apparent noon which should be recorded [in an]gle books, not watch times, which give vast trouble afterwards.

3. I would advise your having small sight vanes attached to the top of your lamp boxes, with trestles of sufficient height to raise the centre of the Heliotrope aperture to the usual height of the axis of your large Theodolite. By this means you will gain the following advantages:—

1*st.*—Your Heliotrope and lamp will be raised above the tower, and the additional height will improve the appearance of the object.

Lamps not being used in Topographical surveys, these remarks are so far inapplicable, but the height of the centre of Heliotrope or other object observed may be made equal to the height of the transit axis of the Telescope so that the eye and object corrections may cancel each other by being equal.

2*nd.*—The sight vane, being attached to the heavy lamp box, will be steadied thereby.

3*rd.*—Both being in perfect adjustment simultaneously, the lamp can be lit exactly at sunset, and all hurry and confusion in setting the lamp box avoided.

4*th.*—The height of eye and object being identical, you can without any trouble calculate, in the field, the height of your stations and satisfy yourself of their correctness on the following principle. In any triangle $A\ B\ C$, if you take the height of A as zero, and the comparative height of A to B and C to B an[d] A to C, the result of levelling round the circuit should reproduce zero for the height of A Good observations should not give an error of more than 1 or 2 feet in a circuit of 8 sid[es] To carry out this principle efficiently, you should have heavy well-made plummets, you must provide yourself with in due time.

4. Heavy plummets are also necessary for plumbing towers where reference is made to the lower mark. You can either make this reference the usual practice, or place a temporary well-centered mark at top, taking care to ensure identity, and measuring the height of towers yourself, so that the results may all be referrible to the mark at the ground surface.

5. It sometimes happens that the height of an inaccessible point is required to be derived from a vertical angle observed to it from a great station. The principle of computation in such cases is explained in the Manual, Part III, Chapter XIX, and requires no further elucidation except as regards terrestrial refraction.

6. There are no certain rules for estimating terrestrial refraction, but with care and attention a much nearer approximation may be made than if all consideration of circumstances was neglected. Reciprocal observed verticals, compared with the contained arc, give the true sum of the refractions at each end of a ray, which sum, divided by two, is the mean refraction deduced by observation. Dividing this mean refraction by the contained arc, we get the ratio of mean terrestrial refractions in terms of the angular distance or contained arc, but as the value of this term differs according to the radius used in computing it, the ratio of refraction will also vary accordingly. Due discrimination must therefore be used in applying such ratios to single verticals, for the same kind of radius of curvature must be used, as was employed in deducing the ratio, *viz.*, either the normal, the meridional radius, the mean radius, or the true radius of curvature, due to the oblique arc.

7. At the northern extremity of the great arc, the mean terrestrial refraction was found to be nearly [illegible]th of the contained arc, computed with the normal as radius, but this ratio is applicabl[illegible] to dry weather and peculiar local circumstances.

8. In the [illegible]rjiling operations on the other hand, the mean terrestrial refraction was found to be [illegible] of the contained arc, similarly computed, or $\frac{1}{12.8}$ of the same arc computed by the [illegible]hich radius of curvature. These ratios are, however, applicable to a very moist climate [illegible]d the months of October and November.

9. [illegible]e mountain operations crossing the Himalaya, all the stations of which series were g[illegible]y elevated above the sea, some of them attaining an altitude exceeding 17,000 feet, t[illegible] nean terrestrial refraction was found to vary with the season, as will be seen from [illegible]owing statement, the ratios in which were computed with a mean radius of curvature [illegible]valent to the radius of an oblique arc of 45° azimuth:—

March.	*April, May, June.*	*July, August, September.*	*October.*
0·06	0·07	0·08	0·06

10. The annexed memorandum exhibits the mean terrestrial refractions given by great Trigonometrical operations in the Jhelum and Rawulpindee districts, the contained arc being computed with a mean radius of curvature, *i.e.*, mean between normal and meridional radius.

11. This table exhibits the mean ratio for terrestrial refraction proper to be used in the locality indicated, and similarly, the proper ratio should be deduced for every other locality and season from the principal operations.

12. It will, however, sometimes occur that an inaccessible point has been observed from a great number of stations at very different distances, varying perhaps as 2 to 1 or upwards. Such single vertical angles, repeated at variable distances, will furnish a most satisfactory check, for it is clear that all the values of the height of an object should be identical. If, however, the greater distance gives the greater height, then too little correction has been applied for refraction. On the other hand, if the greater distance gives the less height, then too much correction has been applied, and the ratios may be altered judi[illegible]sly to produce consistent results. On finishing the back observations to towers or other st[illegible]tions, [illegible] tumulus of earth or pile of stones should be made at top, so as to prevent rain getting down the central aperture, or isolating annulus, and thus speedily destroying the tower. The vault of access to the basement mark should also be closed and the ramp cut away. These precautions have been mentioned before in my paper on towers and previous instructions, but still I find they cannot be too strongly insisted on.

APPENDIX TO H.

Memorandum of Mean Terrestrial Refractions in the Jhelum and Rawulpindee Districts—Season 1851-52.

Eye Stations.	Object Stations.	Ratio of mean Terrestrial Refraction to contained Arc, computed with a mean Radius of Curvature.	Months in which observed.
Jogi Tila	Mongri	·068	Nov. and Jan.
	Jaoli	·066	Nov. and Dec.
	Kundi	·071	April and Nov.
	Kudiali	·070	April and Nov.
	Daolatnagar	·067	November.
Jaoli	Mongri	·069	Dec. and Jan.
	Soorla	·070	Dec. and Jan.
	Kundi	·071	April and Dec.
	Khagriana	·074	December.
	Nerh	·076	December.
Nerh	Kundi	·072	April and Dec.
Khagriana	Nerh	·074	December.
	Soorla	·082	Dec. and Jan.
	Loiset	·078	Dec. and Jan.
	Gandgarh	·074	Dec. and Jan.
Loiset	Gandgarh	·083	January.
	Adjar	·069	January.
	Kaloo	·068	January.
	Pathrijala	·072	Jan. and Feb.
	Soorla	·070	January.
Adjar	Gandgarh	·084	January.
	Kaloo	·076	January.
Kaloo	Pathrijala	·050	February.
Pathrijala	Jhamut	·069	Feb. and March.
	Pari	·065	Feb. and March.
	Soorla	·070	Jan. and Feb.
Soorla	Sidhr	·070	February.
	Pari	·066	February.
Taman	Pari	·060	Feb. and March.
	Jhamut	·064	March.
	Bani	·066	March.
	Sakesir	·062	March.
	Jatla	·046	March.
Jatla	Sidhr	·063	March.
	Sakesir	·065	March.
Sakesir	Bani	·069	March.

Abstract of the Mean Terrestrial Refraction in the Jhelum and Rawulpindee Districts.

	November.	December.	January.	February.	March.	April.	REMARKS.
Mean...	·069	·073	·074	·065	·063	·071	The ratio for April seems doubtful, depending on 4 results only, and those mixed u[illegible] with November.

These are min[illegible] terrestrial refractions.

Observed by G. LOGAN, ESQ., *1st Assistant, G. T. Survey.*

I.

FINAL PROFESSIONAL REPORT OF THE SURVEY AND CONSTRUCTION OF THE MAP.

Heads of subjects to be discussed.

1. ... orders and instructions for the Survey to be briefly referred to.

2. The instrumental equipments, of which a return should be made, particularizing their values and condition at the outset and termination of the work.

3. ... nominal statement of the Surveyors employed, the quantity of work achieved by each, their length of service, &c.

4. Area surveyed, with cost of execution and rate per square mile.

5. A narrative of the operations describing the date of taking the field, and time occupied in field work. Method of procedure, value of the unit of measure, whether derived from the G. T. Survey or from independent bases. Determination of point of departure, if fixed independently, how? or the precautions taken to have it fixed hereafter by the Great Trigonometrical Survey. The steps taken to form a connection with the great triangulation by using its marks, or leaving marks for future reference. The determination of initial azimuth if not derived from the G. T. Survey. The verification processes followed, such as angular proofs:—

1st.—By geometrical conditions.
2nd.—By verificatory azimuths.

Linear proofs:—

1st.—By verification measurements.
2nd.—By errors on closing.

The result of these checks to be stated.

6. An account of the office duties, specifying hours of business; whether all arrears have been brought up, or how much remains in hand. Whether the field-books have been brought up in duplicate, so as to be ready for submission.

7. Whether the Survey is complete in all Topograhpical details, or only partial, and what precautions have been taken to prevent omissions.

8. Remarks on the details, drawing, projection and construction of the map, and how far the character of the country has been successfully represented.

9. An account of the boundaries, general and subsidiary.

10. Geographical, Historical and Statistical notes.

K.

DESPATCH OF THE HONOURABLE THE COURT OF DIRECTORS ON STATISTICS.

Copy of a Letter from the Honourable the Court of Directors (Statistical), No. 6 of 1846, *dated London, the* 3*rd June* 1846.

1. The great practical importance of Statistical enquiries, and the attention which they now receive from the most enlightened European Governments, have induced us to take measures for investigating the Statistics of the countries under our administration, and for arranging and preserving, in a form convenient for reference, the information which may be attainable.

2. With the view of accomplishing these ends, we have formed a Statistical Department in our Home Establishment, in which the requisite enquiries will be conducted, and the materials thereby obtained classified and compared.

3. The voluminous Records and Documents in our possession contain a vast amount of Statistical information, and the labors of the new Department will, in the first instance, be directed to extracting and rendering it available for reference; these duties, which have already commenced, will continue for a long period to claim a large share of the time and attention of the Department, but the results will be imperfec by the co-operation of our Governments in India, in collecting and transmitting stical information, we are enabled to remedy the defects, correct the inaccuracies, as the condition and circumstances of all countries are in many respects constantly ng, to note the changes which time or other causes may produce.

4. We do not doubt that our servants will cheerfully afford their assistance purposes, and as the aid which they may render in this respect is not intended, a not be permitted to interfere in any degree, with their ordinary duties, no detrime arise to the public service, but, on the contrary, much advantage may be expected the transmission home of such information as to local details, which so many of our servants cannot fail to possess.

5. Information will be most desirable on such subjects as the following:

LAND.—Area.
Geological structure.
Natural aspect.
Soil.
Atmosphere and climate.
Productions.
Modes of cultivation.
Prices of principal products.
Tenure and occupation.
Modes and rate of assessment.
Labor employed, and its remuneration.

—Navigable rivers.
Description of.
Length of.
How far navigable.
Vessels employed on them.

LAKES.—Description and situation.

CANALS.—Their purposes.
Length and depth.
Vessels employed on them.
Cost and return on the outlay.
Wells and tanks.
Means of irrigation in each district.
Harbours, and shipping frequenting them.

CITIES.—Towns and villages.
Situation and general description.
Number of houses, and whether Pukha or Kacha.

POPULATION.—Numbers of people of different descriptions.
Employment.
Languages.
Condition.
Health and disease.
Ditto of troops, especially with presumed causes of health, or diseased state, and the treatment (not strictly medical) found to be useful.

WEALTH.—Education, and method of pursuing it.
Charitable institutions not educational.
State of litigation and of crime.
ice, number, remuneration and efficiency.
—Manufactures.
Capital employed.
Imports and exports from official sources.
Exchange.
Weights and measures.
Coins.
Banking operations.
Lending and borrowing.
Modes of transit and communication.
By land.
By water.
Impediments, and their duration.
Fords, ferries and bridges.
Postal arrangements.
Taxation.
Sources of revenue, and produce of each tax.
Mode of collection.
Number in sebundy or other corps, engaged in collecting revenue.
History and antiquities, facts illustrative of more recent history, and of changes, political or agricultural.
Public buildings.

6. We need scarcely observe that in Statistical investigation, the most rigid accuracy as to matters of fact is indispensable. Erroneous information will be worse than none, because it can but tend to mislead.

7. There may be some subjects, especially those relating to Physical Science, with which our servants generally may not be minutely acquainted, and no statement on these or any other matters of inquiry will be of any value, unless they be both precise and accurate. Where the requisite measure of scientific knowledge is not possessed by others, it may perhaps, in many cases, be supplied by our Medical Officers, and their aid will, we doubt not, be cheerfully rendered whenever required.

8. In conclusion, we direct attention to the following general instructions.

9. In all cases, where practicable, reports should be the result of the personal knowledge of the officer reporting, and where such is the fact it should be mentioned.

10. Where, from any cause, the personal knowledge of the officer cannot be extended to any object of inquiry, the authority on which the reported facts rest, must invariably be stated, either in the margin, or in the body of the report.

11. When estimates only can be furnished, the grounds of each estimate must be stated, and the reason for adopting it.

12. Where information is orally given, it should be committed to writing at the time, in like manner personal observations should be recorded at the moment of making them.

13. In addition to the names by which places are known among Europeans, it would be desirable that the original names should be given, both in the Devánágari* and Urdu character, according to the best authorities, especially local and native.

* The Proclamations and State Advertisements in the *Calcutta Gazette* are usually printed in the Devánágari as well as in the Urdu or Arabic character.

14. In regard to coins, weights, and measures, care must be taken to preserve uniformity as to valuation, comparison, and conversion, and to ensure this, Prinsep's Useful Tables may be taken as a guide.

15. Where any material variations exist in different parts of any country, or divisions of a country reported on, the nature and limits of such variations should be precisely pointed out.

16. It will be observed that the greater part of the instructions above are designed to ensure accuracy, the importance of which we have already adverted to. It is the more necessary to dwell upon this point, inasmuch as some previous attempts to afford Statistical information are unsatisfactory, because obviously incorrect.

On Observations with Theodolites or Altazimuth Instruments. By Colonel J. T. Walker, R.E., F.R.S., Superintendent of the Great Trigonometrical Survey of India.

Extracted from "Hints to Travellers," published by the Royal Geographical Society. Third Edition. 1871.

In the opening pages of these Hints (to Travellers), lists of instruments have been given which travellers of little experience are recommended to provide themselves with, and the sextant has been more particularly recommended, as the traveller will have opportunities of practising with it under the tuition of the officers of the ship which is conveying him to his destination. The suitability of this instrument for observations, both on land and sea, is thus a great advantage for any person who has not had an opportunity of learning the use of his instruments before starting on his expedition; and should he not have a sufficient knowledge of the methods of reducing the observations, and calculating the results, he will find the simplest and easiest rules for his guidance in the several works on navigation specially written for the reduction of observations with sextants by persons of little or no knowledge of the principles on which the rules are based. The inexperienced traveller can scarcely be expected to attain much accuracy in his observations and reductions, but should he explore unknown regions, he may be able to acquire valuable information, the immediate interest of which may be very considerable; but his results must necessarily be of a preliminary nature, and be liable to be largely corrected, or altogether superseded, by the operations of subsequent explorers.

But the extent of the regions of *terra incognita* in which inexperienced travellers can operate with the greatest advantage is constantly becoming more and more narrowed and diminished, and Geographical science now-a-days frequently requires that the rough outlines which have hitherto sufficed for her purposes should not only be amplified and filled in, but rectified by more exact and reliable observations. The traveller must, in such cases, be provided with an instrument of greater capabilities than the sextant, and he should have thoroughly learnt the use of this instrument and the method of reducing the several kinds of observations which may be made with it before he commences operations. If he has no better instruments nor greater skill than his predecessors, his results may differ widely from theirs, but they will not be more worthy of confidence, and, while causing much perplexity and inconvenience to Geographers, they will only exhibit with certainty the degree of uncertainty that is still attached to the problem under investigation.

An altazimuth instrument—or a theodolite possessing a complete vertical circle as well as a horizontal circle—is in many respects superior to a sextant. *1st*, it measures horizontal angles directly, thus avoiding the labor of reducing oblique angles to the horizon; and a round of several angles can be measured with far less trouble than with the sextant. *2ndly*, it measures small vertical angles of elevation or depression of objects which frequently

could not be seen by reflection from a mercurial horizon for the measurement of the double angle by a sextant. 3*rdly*, its telescopic power is usually far higher than that of a sextant. 4*thly*, it may be so manipulated as to eliminate the effects—without in the first instance ascertaining the magnitudes—of certain constant instrumental errors, such as excentricity, collimation, and index errors. And 5*thly*, the influence of graduation errors may—when great accuracy is required—be reduced to a very considerable extent by systematic changes of the zero settings of the horizontal circle.

The disadvantages of the altazimuth instrument as compared with the sextant are its greater cost and bulk and weight; but in many instances these disadvantages will be more than counterbalanced by its superior capabilities.

Messrs. Troughton and Simms have favored me with the following details regarding prices, weight, and Telescopic powers of these instruments as constructed by themselves :—

	Weight of, with Box.	Weight of Stand.	Price.	Telescopic Powers.	Readings of Verniers.	Details.
	lbs.	lbs.	£ s. d.			
7-inch (radius) sextant..	7	..	12 0 0	5 to 10	10″	
* Artificial horizon	5 to 10	..	....	....	....	
4-inch (diameter) transit theodolite	13½	9	23 0 0	9 ,, 12	1′	Without transit axis level and lamp.
5-inch ditto ditto ..	25	10	32 10 0	12 ,, 15	30″	With transit axis level and lamp.
6-inch ditto ditto ..	31	12	40 0 0	12 ,, 18	20″.	Ditto ditto.

The Messrs. Casella construct certain very light and cheap altazimuth instruments, with 3-inch circles, power 5, weight with box 4lbs., weight of stand 3½lbs. divided to 1′ price under 20*l*.

For astronomical observations the sextant is decidedly preferable to very small altazimuth instruments, but the latter are to be preferred for the measurement of horizontal angles and small elevations or depressions.

The traveller must necessarily adapt his equipment to his requirements and the facilities he will possess for carrying his instruments about. He may find it convenient to employ a sextant for astronomical, and a very small light altazimuth for terrestrial observations. But whenever practicable, an altazimuth of moderate size, which may be used as a universal instrument, would undoubtedly be the most convenient and satisfactory.

The instrument which I would recommend for geographical explorations, as being well adapted for astronomical and for terrestrial observations, and not very bulky, is the 6-inch transit theodolite by Messrs. Troughton and Simms: several of these have been used in explorations connected with the operations of the Great Trigonometrical Survey of India, and have given great satisfaction, being sufficiently accurate for all desirable purposes, and not too heavy to be easily carried. These instruments are adapted for determinations of time and longitude by the method of zenith distances, and also by that of meridional transits; the former being best suited for the traveller when he can only devote a few hours to the operations the latter when he is halting for a long time at one place: the two methods lead to strictly independent results, so that when both are employed they serve to check each other. The instrument is also well suited for latitude and azimuth observations; in fact, it can be employed in any of the investigations which an explorer may have to undertake by means of astronomical observations. On the other hand, as an instrument for

* The weight of a tripod stand, as described in "Outfit" (p. 8), would be additional.

the measurement of terrestrial angles, whether horizontal or vertical, it is very valuable, and far superior to any sextant, not only being more conveniently manipu[l]ated, but possessing telescopic powers which permit of the detection and identification of objects that would often be sought for in vain with a sextant.

Trigonometrical operations are, as a rule, far simpler and more easily re... , and lead to more accurate results than astronomical observations. A continuous triang... on, or a traverse with measured angles and distances, is necessarily impossible when explorer has to pass through a country very rapidly; but he may frequently remain fo... ral days at one place, and may then have opportunities of greatly extending the ... of his operations by executing a triangulation. Suppose him to be in view of a ran... hills which he may not have an opportunity of exploring, distant, say 50 to 100 mil... have already endeavoured on his line of march to fix points on the range by bearin... from the absence of prominent landmarks has found a difficulty in identifying the poin... observed, and thinks he may have mistaken one hill for another in consequence of their changes in appearance as viewed from positions at some distance apart. If, during his few days' halt, he can manage to do a little triangulation, he may fix the general outlines of the entire range relatively to his halting-place with very respectable accuracy. He has first to measure a base and determine by triangulation the positions of three stations lying in a direction nearly parallel to that of the range, and at distances of 2 to 5 miles apart; then at each of these stations he must measure the angles between the other stations and a series of points on the entire length of the range;* though no very prominent landmarks may be visible, still the telescope will show a number of objects—trees, masses of rock, and peculiarities of the ground—sufficiently clearly to permit of their being recognized at stations of observation which are so close to each other; and though the triangles will be very acute-angled, the angles may easily be measured with sufficient accuracy to give the distances of the points on the ranges from the stations of observation with a small percent-age of error, whenever the marks are fairly identified; and as there will be two triangle to each point, and, therefore, double values of the side common to both triangles, any mist...—whether of identity, or of reading, or calculation—will be at once shown up.

The 6-inch *transit* theodolites of the Indian Survey† which have been used in milit... expeditions and explorations are specially provided with a pair of micrometers in eyepiece of the telescope, for the purpose of measuring small angles, and more pa... those subtended by objects of known dimensions, by means of which the distance betwe... the object and the observer is readily deduced. The system of micrometers is moveable through an angle of 90°, so as to permit of the measurement of either a horizontal or a vertical object. With the aid of this appliance, the instrument can be employed in carrying on a traverse without using any direct measuring apparatus, such as a chain or perambulator, the distances to the back and forward stations being determined by measuring the

* He should make a sketch of the outline of the range in his book of observations; and as he will probably be unable to ascertain the names of the hill summits at such a distance from them, and many of them may have no names, he had better number them in the order in which they are observed, and refer to them always by these numbers, until he can confidently replace a number by a name. Exaggerated sketches of the outlines of the objects intersected by the telescope are frequently of use to facilitate identification on proceeding to the next station.

The positions of places situated within or beyond the range of hills, which are invisible to the traveller, but are known to his native guides and Assistants, may frequently be determined by making a native point the theodolite, as a gun, in the direction of the place, and state its distance beyond or on this side of the range. The guides will often be found to possess a remarkable knowledge of locality, and I have frequently known the independent pointings of different men towards distant invisible objects to coincide together very closely, as was shown by the readings of the azimuthal circle.

† See "Subtense Theodolite" described at page 132, "Manual of Surveying."

angles subtended by poles of known length, which are set up at the stations. In hilly and broken ground, in crossing rivers or other obstacles, and generally wherever a direct measurement is impracticable, this method of procedure is most convenient. It was adopted by Captain Carter, R.E., in his Survey—with one of these instruments—of the line of country passed over by the British army in the Abyssinian expedition. Captain Carter carried a traverse from Adigerat to Magdala, a distance of nearly 300 miles, without any break of continuity, the daily rate of progress averaging 5 miles, and being occasionally as much as 8 miles. The difference of latitude between the origin and terminus as determined from the traverse operations only differed by about a quarter of a mile from the value determined astronomically.

Whenever a halt occurred in the movements of the army, the instrument was used as a theodolite in triangulating to fix the positions of all hills and other prominent objects around the halting-place; it was also used for various astronomical observations.*

REMARKS ON THE MANIPULATION OF ALTAZIMUTH INSTRUMENTS.

Observations with these instruments should always be made in pairs, with the face of the vertical circle alternately to the right and left of the observer. Thus, supposing that in the first observation, or round of observations, the face of that circle is to the right of the observer, the telescope should be immediately afterwards moved through 180° in azimuth, and turned over in altitude, which will bring the face of the circle to the left of the observer, and then a second observation, or round of observations, should be taken; the mean of the two measures, face right and face left, will be free from collimation, index, and other instrumental errors.

In measuring horizontal angles between objects of nearly the same altitude, as landmarks not much above or below the horizon, a change of face is not absolutely necessary, and may be dispensed with if the observer is hurried; but when such angles are measured between objects of very different altitudes—as a terrestrial referring mark and a star—and whenever altitudes are measured, whether of terrestrial or celestial objects, the observations should invariably be taken in both positions, alternately "face right" and "face left" and the final result deduced from the mean, in order that the instrumental errors may be eliminated. There is no necessity to determine the magnitude of these errors, as in the sextant; in an instrument which has to travel far over bad ground the adjustments are liable to alter from time to time, but they are not likely to alter in the interval between two consecutive observations, and the errors arising therefrom will be eliminated in the mean of the pair.

In what follows regarding *astronomical* observations with these instruments, a complete observation will be understood to imply the mean of a pair of observations, one with face right, the other with face left, taken continuously without any considerable pause between them, the entire operation being considered as one observation.

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* These instruments being furnished with a pair of micrometers, which can be used either horizontally or vertically, are all the more valuable for astronomical observations, for the micrometers give two additional wires over which the stars may be observed, and these wires can be set at pleasure to any distance from the fixed wires in the diaphragm which may be best suited to the rate of movement of the star. For pairs of observations—face right and face left—no reductions to the centre wire are necessary; and thus greater accuracy is obtained with very slight additional trouble of observing, and still less of com-

DETERMINATIONS OF *Time*, *Azimuth*, *Latitude* AND *Longitude*, WITH A TRANSIT THEODOLITE.

The transit theodolite may be employed either as a transit instrument or as an altazimuthal instrument; it is adapted for all astronomical observations, excepting those of "lunar distances," which can only be performed by a sextant or a reflecting circle, and occultations, which require larger telescopes.

Thus a description of each of the various kinds of observations which can be made with transit and altazimuth instruments, with full details of the methods to be employed in the corresponding reductions, would fill a volume, and be much more than is required for a book which merely purports to give hints to travellers. Those who wish to obtain full particulars of each of the several methods of observation, and of the reductions, ca better than study Chauvenet's "Spherical and Practical Astronomy," which is on most valuable works on the subject in the English language: it gives ample instructions observations of all kinds, the rudest and most hurried, as well as the most refined and elaborate, and it supplies corresponding formulæ, approximate as well as rigorous, for the reduction of the observations.

As these Hints are merely intended to indicate the simplest and most expeditious methods by which a traveller who is able to carry a suitable altazimuthal instrument about with him can take the astronomical observations which are essentially necessary for his geographical explorations, they will be restricted to determinations of time, latitude and longitude, by the measurement of zenith distances, and of azimuths by horizontal angles; formulæ—some approximate, but all sufficiently rigorous for the purpose, and adapted mostly from Chauvenet—will also be given, for the reduction of the observations.

Latitude Observations, the time being unknown.—The instrument being duly levelled and brought approximately into the meridian, set the telescope on any star, or on the sun, when approaching culmination, and follow it until the maximum altitude is reached; take the zenith distance reading on the vertical circle, change face quickly, and make a second observation; the mean of the two will be a "complete observation" of zenith distance. Two or three pairs of observations may be taken to circumpolar stars, as their zenith distances will not alter sensibly during an interval of a quarter to half an hour; for other stars the observations should be restricted to one pair, and stars should not be observed when within 25° of the zenith. A single pair of observations with the 6-inch transit theodolite should give a determination within 20″ of the truth; greater accuracy may be ob by observing additional stars, more particularly when the stars are selected so as to form pairs of nearly equal distance from the zenith, north and south.

Latitude Observations, the time being known.—(1.) Observe the zenith distance of the Pole-star in any position, and reduce to the meridian by the tables in the "Nautical Almanac."

(2.) Take circum-meridian observations of the zenith distance of any star, alternately face right and face left, and note the time of each observation; compute the reduction of the zenith distance at the time of observation to the distance on the meridian, and take the mean of the reduced results as the determination of the meridional zenith distance. Three or four pairs of observations may generally be made in succession to the same star, but the nearer the star is to the zenith the more accurately should the times be known—it is not desirable, therefore, to observe stars within 10° of the zenith. Here, too, pairs of north and south stars of nearly equal zenith distance will give the best results.

Time.—Take pairs of observations of the zenith distance of a star, noting the chronometer time of each, and adopt the mean of the times as the time corresponding to the mean zenith distance, with which, the latitude of the place, and the star's declination, the star's hour angle must be computed by either of the well-known formulæ: thus the local time and the chronometer error will be determined. For these observations stars are most favorably situated which are easterly or westerly, and not very near either to the horizon or to the meridian; and greatest accuracy is obtained when two stars are observed at nearly

the same altitude, one to the east, the other to the west. With a pair of observations the chronometer error should be determined within one second when a 6-inch transit theodolite* is used.

Longitude.—Take pairs of observations of zenith distance on a star for the determination of the local time and chronometer error, then take other pairs of observations of zenith distance of the moon; in each instance adopt the mean of the chronometer times as that of the "complete observation" of zenith distance. Both moon and star should be easterly or westerly, and not very near either to the meridian or to the horizon. The operations should commence and close with star observations, in order that the chronometer rate may be duly ascertained and allowed for. Ten pairs of observations to the moon and six to stars ought not to occupy more than four hours, and they should give a very fair result, usually within 8 miles of the truth. The effect of instrumental errors will be materially reduced when the stars and the moon are on the same sides of the meridian and at nearly the same zenith distance; if time permits, observations should be taken both east and west of the meridian, and both before and after full moon.

Azimuth, time and latitude being unknown.—Observe the angles between a referring mark† and a star when the star is at the same altitude east and west of the meridian; several pairs of observations may be taken at consecutive altitudes, half with face right and half with face left. Or the angles may be measured between a referring mark and a circumpolar star at the times of its maximum elongations east and west. The mean of the two angles at opposite positions gives the angle between the star and the meridian, and thence the azimuth of the referring mark, without any calculations whatever. In the first case, however, an interval of several hours must be allowed to elapse between the observations east and west; and as twelve hours must necessarily elapse between the opposite elongations of a circumpolar star, few stars will ordinarily be visible at both elongations.

It may therefore be desirable to adopt a third and more expeditious method, as follows:—Measure the angles between the referring mark and *two* circumpolar stars at their respective elongations, selecting stars which are nearly in opposition or nearly in conjunction, and will attain their maximum elongations at nearly the same time, that the observations may be completed quickly; then with the observed value of the angle between the stars, and the given declinations of the stars, the azimuths of both may be readily computed, as shown below. See "Observations for Azimuth."

Azimuths, latitude being known.—Observe the angle between the referring mark and a circumpolar star at maximum elongation, and compute the azimuth of the star. To stars near the pole two or three pairs of observations, face left and face right, may be taken before the star moves sensibly from the position of maximum elongation.

Azimuth, latitude and time being known.—Any star may be observed in any position, but the best results will be obtained when a circumpolar star is observed at a short distance from the elongation; the angle between the position of the star at the observation and at the elongation may be computed by the formulæ given at pages liv, lv. "Observations for Azimuth."

General Remarks.—The observed zenith distances should always be corrected for refraction; barometer and thermometer readings should, therefore, be taken during the observations, for the better determination of the refraction. When no barometer is at hand, the

* At a trial of one of these instruments for the Indian Survey, the results of six pairs of observations on east and west stars fell within an extreme range of 0·4 of a second of time; the stars were, however, observed on the wires of the two micrometers as well as on the fixed wire of the diaphragm.

† A good referring mark may be made of a cross with a hole of ¼ to ½ an inch in diameter in the centre, to which observations can be taken by day and by night, being rendered visible at night by a bull's-eye lantern placed behind the hole and directed to the observer. The stem of the cross should be vertical, and driven firmly into the ground. The distance from the station of observation should be at least half a mile, and the station should be marked by a pin driven into the ground, over which the theodolite must be carefully centered whenever set up for horizontal observations.

height of the station of observation should be given, as deduced by the boiling point or otherwise, or even approximately estimated. It may be well to remember that in dete mining latitude, errors of refraction may be eliminated by observing pairs of north and south stars of the same zenith distance.

FORMULÆ AND EXAMPLES.

Latitude by Circum-meridian Observations of a Star.

Let ϕ be the true latitude, ζ the true zenith distance on the meridian, ζ_0 the observed zenith distance corrected for refraction, δ the declination of the star,* ϕ_0 an approximate value of ϕ, $= \delta \pm \zeta_0$, t the hour angle of the star.

$$\text{Put } A = \frac{\cos\phi_0 \cos\delta}{\sin\zeta_0} \text{ and } m = \frac{2}{\sin 1''}\sin^2 \tfrac{1}{2}t.$$

$$\text{Then } \zeta = \zeta_0 - Am, \text{ and } \phi = \delta \pm \zeta.$$

The values of m are tabulated in Chauvenet's 'Astronomy.'

Alternative forms of m, adapted for various logarithmic tables.
$m = \text{cosec } 1'' \text{ versin } t.$
$= \cdot 00055t^2$, when t is given in seconds of time.
$= 2t^2$ nearly, „ „ minutes „

Supposing n observations to be taken, then, since A is constant,

$$\zeta = \zeta_0 - A\frac{m_1 + m_2 + \quad . \quad . \quad . \quad . \quad . \quad + m_n}{n}.$$

Example.—CIRCUM-MERIDIAN OBSERVATIONS FOR LATITUDE TO β URSÆ MINORIS, NORTH OF THE ZENITH.

Face.	Circle Readings.†	°	′	″	Mean Zenith Distances of Pairs of Observations. °	′	″	Chronometer. H.	M.	S.	of Time.	
Left	Alt.	64	10	20	35	47	38	14	45	47	7·2	
Right	Z.D.	35	45	35					47	1	6·0	
„	„	35	45	0	35	47	5		48	55	4·1	
Left	Alt.	64	10	50					51	30	1·5	
„	„	64	11	0	35	47	8		54	37	1·6	
Right	Z.D.	35	45	15					56	22	3·4	
„	„	35	45	30	35	47	25		57	43	4·7	
Left	Alt.	64	10	40					58	48	5·6	54
„	„	64	10	30	35	47	40	15	0	18	7·3	53
Right	Z.D.	35	45	50					2	10	9·2	85
	Mean ..				35	47	23				Mean ..	31·6
	Refraction ..					+	42					
	ζ_0 =				35	48	5					
	$-Am$ =					—	22					
	ζ =				35	47	43					

$\phi = 38° 58' 54''.$

$31{\cdot}6 \times 2 = 63{\cdot}2.$

Data.

		H.	M.	S.
Æ of Star	..	14	51	14
Chron. Error	..	+	1	46
Chron. Time of Transit.		14	53	[illegible]
		°	′	″
	.. =	74	46	37
ζ_0	.. .. .. =	35	48	5
ϕ_0	.. .. .. =	38	58	32

log cos ϕ_0	9·8906
log cos δ	9·4192
log cosec ζ_0	0·2330
log A	9·5429
log 63·2	1·8007
log Am	1·3436

For the above formula t should be less than 20 minutes, and ζ greater than 10°.

* When the sun is observed, the declination corresponding to the mean of the times of observation should be used.

† The circle readings will be alternately altitudes and zenith distances $\pm$ the index error of the instrument, which error is eliminated in the mean of a pair of observations.

Longitude by Lunar Zenith Distances.

The local time and the chronometer error having been determined from the star observations

ζ_0 = the observed zenith distance of the moon's limb.

Θ = the local sidereal time of the observation of ζ_0.

L_1 = an assumed value of the longitude.

ΔL_1 = the required correction of L_1.

L = the true longitude $= L_1 + \Delta L_1$.

ϕ = the latitude.

Find the Greenwich time corresponding to Θ and L_1, for which take

δ = the moon's declination.
π = the moon's equatorial horizontal parallax.
S = the moon's geocentric semi-diameter.
} from the 'Naut. Alm.'

Let S_1 be the moon's apparent semi-diameter, and π_1 the corrected parallax;

$$\text{then } S_1 = S + \Delta S, \text{ and } \pi_1 = \pi + \Delta\pi;$$

and the values of ΔS and $\Delta\pi$ may be interpolated from the tables below, which are abridged from Chauvenet.

Also put $\delta_1 = \delta + e^2\pi_1 \sin\phi \cos\delta$, in which $\log e^2 = 7{\cdot}8244$; and let r be the refraction for the apparent zen. dis. ζ_0;

$$\text{and let } \zeta_2 = \zeta_0 + r \pm S_1,$$

$$\text{and } \zeta_1 = \zeta_2 - \pi_1 \sin\zeta_2;$$

then the hour angle, t, is found from the equation

$$\sin^2 \tfrac{1}{2}t = \frac{\sin\frac{1}{2}[\zeta_1 + (\phi - \delta_1)] \sin\frac{1}{2}[\zeta_1 - (\phi - \delta_1)]}{\cos\phi \cos\delta_1},$$

after which the moon's right ascension, Æ, is found by the formula

$$Æ = \Theta - t.$$

The Greenwich mean time corresponding to the moon's Æ must be found from the 'Nautical Almanac;' with this and the local mean time a value of the longitude is determined, which, however, is approximate only, as t is computed with an approximate value of δ depending on the assumed longitude. Put L_2 for the approximate value of the longitude which is thus determined, and

Value of ΔS, always +.

Apparent Zen. Dis. of Moon.	Horizontal Semi-diameter. 14′ 30″	15′ 0″	15′ 30″	16′ 0″	16′ 30″	17′ 0″
0°	[illegible]·7″	14·6″	15·6″	16·7″	17·7″	18·8″
10	13·5	14·4	15·4	16·4	17·5	18·6
20	12·9	13·8	14·7	15·7	16·7	17·7
30	11·8	12·7	13·5	14·4	15·4	16·3
40	10·5	11·2	12·0	12·8	13·6	14·4
50	8·8	9·4	10·1	10·7	11·4	12·1
60	6·9	7·3	7·9	8·4	8·9	9·5
70	4·7	5·1	5·4	5·8	6·1	6·5
80	2·4	2·6	2·8	3·0	3·2	3·4
90	0·1	0·1	0·1	0·1	0·2	0·2

Values of $\Delta\pi$, always +.

Latitude.	Equatorial Parallax. 53′	57′	61′
0°	0·0″	0·0″	0·0″
10	0·3	0·3	0·4
20	1·2	1·3	1·4
30	2·7	2·9	3·1
40	4·4	4·7	5·1
50	6·2	6·7	7·2
60	8·0	8·6	9·2
70	9·4	10·1	10·8
80	10·3	11·1	11·9
90	10·6	11·4	12·2

put β = the increase of δ in a unit of time } at the Greenwich mean time of the observation
and λ = " Æ " } of the moon;

$$\text{also let } a = \frac{\beta}{15\,\lambda}\left\{\frac{\tan\phi}{\sin t} - \frac{\tan\delta}{\tan t}\right\};$$

$$\text{then } \Delta\,L_1 = \frac{L_2 - L_1}{1 + a}, \text{ and } L = L_1 + \Delta\,L_1.$$

These formulæ are demonstrated in Chauvenet, vol. i, pages 383 to 385; and when several observations have to be reduced, they entail less labour of computation than any other formula.

Example.—In latitude ϕ = 38° 58′ 53″ and assumed longitude L_1 = 5h. 6m. west of Greenwich, on May 2nd, 1849, the moon being east of the meridian, the zenith distance of the moon's upper limb was observed to be 57° 47′ 28·5″, when the local mean time was 5h. 33m. 21·6s., and the local sidereal time Θ = 8h. 1[illegible] 14·61s.

Approximate Greenwich mean time, 10h. 39m. 21·61s.
for which we find from the 'Naut Alm.'

δ =	+ 3°	47′	47·6″
S =		15	16·4
π =		56	3·1

and from the tables above given we find

Δ S	=	+ 8·1
$\Delta\pi$	=	+ 4·4
$\dfrac{e^2\pi_1\sin\phi}{\cos\delta}$		+ 14·1

	°	′	″
ζ_0 =	57	47	28·5
r =	+	1	30·9
S_1 =	+	15	24·5
ζ_2 =	58	4	23·9
$-\pi_1\sin\zeta_2$ =		−47	38·1
ζ_1 =	57	16	45·8
δ_1 =	3	48	1·7

With these values of δ_1, ζ_1, and ϕ we find—

	H.	M.	S.
t =	− 3	19	53·64;
but Θ =	8	16	14·61;
whence the computed Æ =	11	36	8·25.

	H.	M.	S.
The corresponding Greenwich mean time for this value of the Æ is ...	10	39	48·7
The local mean time is	5	33	21·6
Whence the approximate long. L_2 is	5	6	27·1

For the Greenwich mean time 10h. 39m. 48·7s. { increase of Æ in 1m. = 2·014s. = λ; " " δ " 10·01″ = β.

Whence a = − 0·3317; and since $L_2 - L_1$ = + 27·1 s.,

$\Delta\,L_1$ = 40·6s., and L = 5h. 6m. 40·6s.

Formulæ for the reduction of Azimuth Observations.

(1.) When a star is observed at an elongation.
Let A be the azimuth, δ the declination, ϕ the latitude,

$$\text{then } \sin A = \frac{\cos\delta}{\cos\phi}.$$

(2.) When a star is observed at a short distance from the elongation.
Let t be the hour angle at the time of elongation,

$$\text{then } \cos t = \frac{\tan\phi}{\tan\delta}$$

Let $d\,t$ be the difference between the hour angles at the times of elongation and of observation, and dA the corresponding difference of azimuth,

$$\text{then } \tan dA = -2 \sin^2 \frac{d\,t}{2} \sec \phi \cot \delta \ \operatorname{cosec} t;$$

whence if $d\,t$ is expressed in *minutes of time*, and κ is a constant,

$$\log \kappa \text{ being} = \cdot 29303 + \log \sec \phi \text{ long} \cot \delta + \log \operatorname{cosec} t,$$

$$dA'' = -\kappa (d\,t)^2.$$

(3.) When two stars are observed at their elongations.

Let their azimuths be A_1 and A_2, and their declinations δ_1 and δ_2,

$$\text{then } \sin A_1 = \frac{\cos \delta_1}{\cos \delta_2} \sin A_2.$$

The value of $A_1 + A_2$ or of $A_1 - A_2$ is given by the observations, $A_1 + A_2$ if the stars are at opposite elongations, $A_1 - A_2$ if they are at the same elongation. Suppose that we have

$$A_1 \pm A_2 = m,$$

$$\text{then } \cot A_1 = \cot m \pm \frac{\cos \delta_2}{\cos \delta_1} \operatorname{cosec} m,$$

$$\text{or } \cot A_2 = \cot m \pm \frac{\cos \delta_1}{\cos \delta_2} \operatorname{cosec} m.$$

*Observations for Azimuth.**—The true bearing of a heavenly body may be obtained by means of a sextant either from observations of altitude or from the apparent time. As the formula for obtaining the latter does not appear in many works on Navigation, it is given :—

Time.	Azimuth.	Month.		Day.			
H. M. S.	° ′ ″	Co. Lat. P. Dist.	° ′ ″				
		Sum.					
		Diff.					
		½ Sum.		Cosec		Sec	
		½ Diff.		Sine		Cosine	
		½ Hor. ∠		Cotang		Cotang	
			Arc 1 = Tang				
Cor.			Arc 2.			Tang Arc 2	
	App. time						
	Hor. ∠		☉ true Az. (= Arc 2 — Arc 1.) ☉ mag. Az.				
	½						
	½ hor. ∠ in Arc.		Variation.				

NOTE.— Arc 2 is of the same affection as the ½ polar dist. and Co. Lat.: when one is acute so is the other, and *v. v.*

Add arcs 1 and 2, when polar dist. is greater than Co. Latitude.

Subtract " " less " "

* By Francis Galton, Esq., F.R.S.

The angular distance between the Pole-star, which is only 1° from the Pole, and any object on the horizon affords an approximate and simple method of obtaining the true bearing: the formula for the reduction of the oblique to the horizontal angle is—

Reduction of Angle.

* and obj.	Cosine
* Alt.	Secant
Red. Angle	Cosine

The bearing of the Pole-star at all times, or any other celestial object, when near the meridian, affords approximate means of obtaining, without calculation, the variation of the compass.

MEMORANDUM ON THE VERNIER CLASS OF THEODOLITES.

AMPLIFIED FROM THE HEADS OF A LECTURE,

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[*Published with the "Topographical Instructions," for the use of the Survey Department.*]

Distinction between Vernier and Reading Microscope Theodolites.

1. The Theodolite, or Altazimuth Instrument, is constructed of various dimensions and according to different designs, but the chief distinction which may be firstly and most suitably noticed, is that which is comprehended between the Reading Microscope and the Vernier Theodolite. In the former instrument, its Readings are obtained by means of Reading Microscopes. In the latter, a most useful invention of Peter Vernier's is employed to encompass the same end. The Vernier Theodolite forms the subject of this paper.

How Theodolites are characterized.

2. It is customary to characterize a Theodolite according to the diameter of its horizontal circle, so that when the latter measures (n) inches, the former is called an (n) inch Theodolite. Thus there are the 5, 7, 8, 12, and 14 inch Theodolites, all of which are usually read by the Vernier. The Reading Microscope Theodolites are the 15, 18, 24, and 36 inch.

Special subject of this paper.

3. Of the Vernier Theodolites enumerated, the 7-inch (Everest's) may be fitly taken as a type or representative in general. The following remarks therefore apply in particular to this instrument, and in those cases where illustration makes it necessary to adopt Theodolites of other dimensions or pattern, the digression from the text will be duly noticed.

Notes for packing, and general remarks on contents of Box.

4. Supposing then that a 7-inch Theodolite locked in its case has been placed before us, that we have opened the box and turned back its lid, thus exposing to view the instrument and its appurtenances as they are packed for travelling. The first step to be taken is, to examine the position of these contents, and to make suitable notes of the same; so that hereafter, in putting the instrument back into its case, one of the most serious sources of accident, arising from the want of such notes, may be avoided. In the present instance we find the Telescope occupying one of the diagonals of the box, the "object end" being in the right hand corner, while the "Face" stands next to the hinged side of the case. It is sufficient to define these two conditions, by marking the letters *O* and *F* respectively on those parts of the boards near which the object end of the Telescope and Face rest. Besides the instrument itself, the following will usually be found in the box.

I. Magnetic Needle and two mill-headed screws for fixing it to the Telescope.
II. Direct (so called) Eye-piece.
III. Plummet.
IV. Ordinary turn screw and pin.

Of these, No. II need rarely if ever be used, for by reason of its four lenses, less light is refracted to the eye than with the inverting (so called) eye-piece, which latter contains only two lenses (1). The plummet on the other hand is absolutely necessary, but occupying as it does a higher place in the box than the Theodolite, care should be taken when placing it in its travelling socket that it does not fall on the instrument. No. IV is a very indifferent screw-driver, whence every careful surveyor should provide himself with both larger and smaller turn-screws of better pattern and temper.

A most important caution.

5. Having enumerated the contents of the box, we proceed to place the instrument on its stand. But before doing so we must gravely caution the surveyor against ever employing violent force in the manipulation of a Theodolite. It is a caution as easy as beneficial to remember, and one which the construction and purposes of the Theodolite peremptorily forbid a violation of. No man yet observed truthful angles or kept his instrument in working order, who employed violence to effect his purpose. When a screw works stiff, or a slide cannot be moved, when the Theodolite itself will not settle into its appointed recesses for travelling, or the lid of the box does not close;—in all these, and every other similar case, be patient, let your movements be gentle. More than one valuable instrument has been irretrievably damaged through a neglect of this fundamental maxim, viz., *never to employ violent force in the manipulation of a Theodolite.*

Placing the Instrument on its stand.

6. Now draw the slides which hold the instrument down, lift the Theodolite and place it on its stand. In performing this process, there is no choice but to hold the instrument by what are termed its *Ys.* This mode of lifting is evidently objectionable, and the heavier and larger the instrument the greater the objection. The most correct way of raising a Theodolite, is clearly by holding its foot screws (2); but these latter are inaccessible in the case of a 7-inch and the small size, and weight of the instrument make the objection named comparatively trivial.

Naming the various parts of a Theodolite.

7. But before proceeding further (3), it is essential that the various parts of a 7-inch Theodolite should be duly named. To this end we begin with the "Foot Screws" of which there are three, working in a "Tribrach." The "Boss" of this Tribrach is pierced with a "Female Axis," in which the "Lower Vertical (or Azimuthal) Male Axis" works, and attached to the Boss of the Tribrach is an arm carrying a "Clamp and Tangent Screw." This brings us to the "Horizontal Plate" of the instrument, which bears the "Graduations" marked on silver; the silver circle being termed the "Limb." The graduations again are read by means of the three "Verniers" and the moveable "Lens" above them; and the fourth arm projecting from the Boss of the "Upper Female Vertical Axis" carries a second clamp and tangent screw. This last mentioned Axis encloses the "Upper Male Vertical Axis." So in succession we arrive at the "Azimuthal Level," from thence to the "*Ys*," within which the "Pivots" of the "Transit Axis" work. Between the Pivots lies the "Telescope," carrying with it two segments of the vertical circle denominated the "Face" of the instrument. The "Verniers" which appertain to these segments carry their clamp, tangent screw and the "Vertical Level" with them, the whole being fixed in position by means of a couple of antagonistic screws, usually termed "clips," which work against a shoulder between them.

NOTE 1.—The weight of the direct Eye-piece overbalances that end of the Telescope. This Eye-piece is sometimes useful as a finder for indistinct objects.

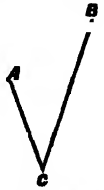
NOTE 2.—The large Theodolites are always raised by the feet, and for Troughton's great Theodolite a lifting apparatus was applied in this country.

NOTE 3.—At this stage, in addition to the notes in para. 4, record the position of the clamps; which in this class of instruments, defines that of the foot screws. In larger instruments, the reading of the circle when packed requires to be noted, and in some cases, a foot screw and its place in the box should be similarly marked.

As in the case of the Azimuthal Verniers the "Vertical Verniers" are read by means of two "Lenses." In the Telescope, we observe the "Eye-piece," the "Object-glass" and its "Cap," as also the large "Milled-head," which, carrying a "Pinion" and working in a "Rack" attached to the "Sliding Tube" of the Telescope, affords the means of nice adjustment for "Focus." Finally, if the eye-piece and the tube within which it fits were removed, there would be exposed to view a "Diaphragm" carrying three "Wires," whereby a point within the "Field" of the Telescope becomes defined. The Diaphragm in turn is held by means of four screws whose Capstan-heads appear around the sliding tube of the Telescope. These four screws are termed the "Collimating screws."

Measurement of Horizontal Angle illustrated.

8. We may now consider generally in what manner an azimuthal ∠ is measured with the Theodolite. For this purpose, see that the lower horizontal clamp is clamped, and that the upper clamp is released. Also since the assumption will probably simplify a rough illustration, let us imagine the pivots of the transit axis raised sufficiently high and the Telescope capable of reading its own horizontal limb when depressed thereto (1). Now let it be required to measure the horizontal angle at C between A and B. Move the Telescope until it intersects A. Then depress the Telescope and read the limb, obtaining by this means a reading of (say) 17°. Next move the Telescope until it intersects B, obtaining by a similar process a reading of (say) 33°. Now since the horizontal readings of most modern instruments increase from left to right, or as an ordinary screw is turned in driving it home, that is *increase* in the order south, *west*, north, east, the $\angle ACB =$ $33° - 17° = 16°$. Hence, it is by a comparison of *non-simultaneous* readings that the Theodolite measures horizontal angles; so that, if intermediate to the two intersections A and B, the limb of the instrument happened to undergo movement, then the readings obtained would be vitiated by this movement, and would be no longer comparative. In other words, if after intersecting A and reading it at 17°, the limb moved in such wise that the line AC would now cut the 19° division, then would the reading of B become 35° and the $\angle ACB = 35° - 17° = 18°$ instead of the real ∠ 16°.



Planes in which the Theodolite measures angles.

9. Thus the Theodolite cannot observe two points simultaneously, as for instance is done with the Sextant; nor yet like the latter instrument can it measure oblique angles. Its measurements can be made in only two planes, *viz.*, a plane perpendicular to the Normal, and the planes perpendicular to that plane. In other words, its measurements can only be made in the horizontal and vertical planes to any point on the earth's surface.

Stability.

10. The inability to observe two points at the same instant creates this indispensable condition, that no movement shall occur in the limb of a Theodolite, while the Telescope is being moved. To ensure this end, it is essential to secure stability of

(1) Ground or site of observation.
(2) Theodolite Stand.
(3) And of the Theodolite.

Stability of ground.

Stability of ground. It is rarely necessary to adopt any extraordinary precautions for 7-inch instruments with the object of securing this end. Usually, the paring of the turf under the legs of the stand is found sufficient. But when the site of observation is artificial, and perhaps composed of both straw and earth; or yet again, when observing on dry sand with a strong wind undermining the legs of the stand, it is occasionally found necessary to isolate the instrument. This may be done by driving three ordinary tent pegs nearly flush with the ground and resting the

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NOTE 1.—Of course this supposition is entirely theoretical.

stand on them, since the vibrations of the pegs in driving them home necessarily causes the isolation required. If required, strike the pegs laterally before driving home, so as to ensure isolation. Tremor and instability of the ground are widely different. The first is momentary and makes no alteration in an intersection; the second leaves permanent displacement.

The Stand and its stability.

11. *The Stand and its stability.* There are three descriptions of Stand used in the Great Trigonometrical Survey of India; two of these being provided with moveable legs, and the third having its legs rigidly fixed in position. For sketches of the two former, see Manual of Surveying, page 70. The fixed Stand is probably peculiar to the Department, and besides being the most stable of the three, it is furnished with three long radiating grooves on its surface, of such length as to accommodate any of the Vernier Theodolites. But in a hilly country, the fixed Stand causes considerable delay, since it is necessary to roughly level a plot of ground capable of receiving the legs of the Stand. The Stands with moveable legs may, on the contrary, be readily put up under almost any circumstances. To secure the stability of any of these Stands, it is only necessary to drive their screws tightly home.

Stability of Theodolite.

12. Stability of the Theodolite depends chiefly on the foot screws, the clamps and tangent screws, but as it is intended to offer a few remarks on each of the parts composing the Theodolite, the stability of the above-mentioned portions will be commented on in due course.

The Foot Screw.

13. The Foot Screw should on the one hand have no sensible shake in its socket, and on the other it should admit of being turned by a force short of what would displace the instrument. This is effected by a slit made horizontally across the female screw, which slit being opened as required, its elasticity keeps the threads in close action with the Foot Screw. This adjustment will be found much improved in the 8-inch and other Theodolites recently constructed.

Similarity of Axes.

14. The Upper and Lower Vertical Axes are so precisely similar in construction that it will be sufficient to consider only one of them, *viz.:*

The Upper Vertical Axis.

15. *The Upper Vertical Axis.* This axis is the frustrum of a cone, the centre portion of which is relieved, so that contact between the male and female axes (1) exists along the ends of the frustrum only. These two axes are necessarily similar, the female axis being simply a male one introverted. The male axis is relieved, to induce a constancy in the bearing surfaces, and hence in their centres. Friction is not lessened by this condition, for since friction varies as weight, it is immaterial what amount of surface is in contact so that the pressure is unchanged. The base of the frustrum is provided with a flange, which shares the superincumbent weight with the cone, and it is one of the essentials of stability, that the axis of revolution should in every case work glibly (2). To this end, take out the screw and nut at the upper extremity of the axis, also remove the clamping screw and its nut, having previously taken off the Telescope from its *Ys.* Now raise the instrument by the *Ys*, and the upper portion will lift readily with the hand. Clean the male and female axes with soft cloth, employing some pure olive oil for the purpose (3). It is at this stage of the operation, that the limb, verniers, clamp and tangent screws should be examined and cleaned.

Of the Limb, Verniers, Clamp and Tangent Screw.

16. The Limb and Verniers should be very carefully brushed free of dust and grit, next washed with a little soap and water, and finally rubbed over with a cautiously prepared mixture of lamp-black (4) and oil. In these processes the tip of the finger alone should be employed. It

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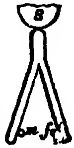
NOTE 1.—Also called Axis and Socket. NOTE 2.—But of course be free from shake.

NOTE 3.—Salad oil is frequently adulterated with Linseed oil, which latter being a drying oil, soon leaves a gelatinous deposit.

NOTE 4.—Made by holding an oiled plate over the flame of a wick dipped in oil. The more smoke the better. The Lamp-black should be made as required, so that it may be fresh and free from grit.

is extremely sensible of grit, and its superior capabilities of polishing are well known. The clamp and tangent screw are of considerable moment in a Theodolite. They are peculiarly liable to be the seat of instability, and on the other hand without their assistance, it would be a tedious and unsatisfactory process to make an intersection at all. The Tangent Screw at one of its extremities works in a collar, and at the other extremity in a female screw. The collar (in the case of the *Upper* Horizontal Clamp) may be called the "moveable point" and the female screw the "fixed point." This female screw is cut in a stud fixed to a brass plate carrying a shoulder, which plate works in its appointed slide in the lower surface of the fourth arm projecting from the boss of the female axis. Again through this arm are cut two slots, in one of which the stud before-mentioned moves, while through the other the clamping screw passes perpendicularly. This last screw next passes through the brass plate, and attaches to a nut, which also carries a shoulder, so that when the clamping screw is clamped, the shoulder of the brass plate and the shoulder of the nut pinch the upper rim of the horizontal circle, and hold it firmly. Whence it will be perceived, that a fulcrum is furnished for the Tangent Screw to act on. Now, since turning the Tangent Screw varies the distance between the fixed and moveable points, and since the former is rendered immoveable by reason of the lower horizontal clamp; the movement created occurs at the collar, and is communicated through the arm, axis, &c., to the Telescope. But by reason of their being constantly used, both Tangent Screw and shoulders become worn in time, and when this happens, what is termed "lost motion" occurs. Otherwise, the screw being loose, it may be sensibly turned before its threads come in contact with the female screw. Or, the bearing surfaces of the shoulders being wider apart than the thickness of the rim of the horizontal plate, they are no longer capable of pinching the latter, and thereby furnishing the necessary fulcrum for the Tangent Screw to act on. In both these cases instability would result. Such sources of instability are occasionally created in the field, at a time perhaps when the surveyor is entirely dependent on his own resources. It may therefore be useful to mention some of the remedies which fall within his reach. In the case of the Tangent Screw, the object to be attained is to keep the fixed and moveable points constantly pressed either together or apart (1), whereby the lost motion will become eliminated. To this end take an ordinary bit of bamboo, slit it partially and adapt the two legs thus produced to the required thickness. Now if *B* be the boss of the female axis, (*f*) the fixed and (*m*) the moveable point, it is clear that the required object may be temporarily obtained, by fixing each leg of this bamboo spring without (*f*) and (*m*); the head of the spring being conveniently placed inwards towards the boss of the female axis. Other temporary remedies may also be named (2), but being uncertain and dangerous experiments, it is wiser not to resort to them. The clamp, on the other hand, is both readily and permanently cured. Take out the nut and grind the surface (*a*) until the shoulders bite. This remedy merely requires ordinary caution in application. Returning to the Tangent Screw, its worm or thread being rather delicate, there is some risk in parting the male and female screws for the purpose of cleaning them. To an unpractised hand, they will be found difficult to fit together again, and being, as remarked, of a delicate formation, it is likely that the union will be imperfectly effected and the screw destroyed. It is therefore a wiser plan to clean the screw by repeatedly moving the female screw as required. There is yet another caution



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NOTE 1.—In several modern Theodolites, this pressure will be found effected by means of a spiral spring.

NOTE 2.—Such as taking out the Tangent Screw, passing a coarse thread over it longitudinally and then introducing the screw into its female screw. Another method is to take out the Tangent Screw, and holding it perfectly perpendicular, head downwards, to give it a suitably strong tap on its point. Whereby the angle of the spiral becomes slightly altered. This latter is a very dangerous expedient, for it may bend the screw and so render it useless.

which may be useful to note. The Tangent Screw is taken to pieces by removing a minute screw, which will be found in the centre of its (Tangent Screw's) head. This little screw serves the important purpose of preventing lost motion between the shoulders in which the collar or moveable point works. If screwed at all too tight, the Tangent Screw can hardly be turned; on the other hand, any looseness between the shoulders and collar creates an equal amount of instability in the Telescope. The Tangent Screw and clamp play an important part in the manipulation of the Theodolite, and are deserving of proportionate attention. The latter should bite fairly, and the former ought to move glibly and effectually. This last condition cannot be secured unless lost motion be eliminated (if necessary) in the fixed and moveable points and in the clamp.

The Upper Vertical Axis resumed.

17. Returning now to the Axis. We have supposed that it has already been cleaned, every precaution to avoid the entrance of sand and grit having been carefully adopted. There now remains to oil the axis before closing it, and for this purpose the best lubricating matter will, it is believed, be found in pure olive oil. The most suitable oil for the axis of an instrument probably depends on the weight (so to speak) to be floated. For a large weighty instrument thicker (though not much more gelatinous) oil may be more suitable, but in the absence of more positive evidence, pure olive oil filtered through blotting paper, will be found to answer for the axis of every instrument, from the 7 to the 36 inch.

The Verniers and general remarks on foregoing.

18. It is objectionable to clean the limb and upper surface of the Verniers of a Theodolite frequently, because the friction must necessarily produce some amount of abrasion. Once a year is generally found sufficient. The adage that "prevention is better than cure" is well suited to these surfaces, for they may be long kept in good and workmanlike order by brushing them free from dust and grit with an ordinarily soft camel's-hair brush. Indeed the habit once acquired, surveyors may be seen brushing the limb almost unconsciously as they walk round and round the instrument. On the other hand, the Upper Vertical Axis and the lower surfaces of the Verniers require frequent cleaning. The latter is easily effected by holding a piece of thin soft cloth on the limb and making the Vernier pass over. But on this and every other occasion, when the Vernier is being cleaned, it must be remembered, that its sharp silver edge is very soft, and that a trifling force will injure it. Verniers should always be wiped *with* the edge, not against it. There are three Verniers in this instrument as already mentioned, and in all cases, whether of Verniers or Reading Microscopes, the number will be found to be an odd one. One of the reasons for this condition may be thus stated. As far as the very rough measurement of an angle is concerned, one Vernier will evidently serve the purpose as well as a larger number, but owing to the imperfections of graduation and errors in estimating minute quantities, a mean reading from three or more Verniers will obviously be more accurate than the reading from one such Index. Now by a process to be hereafter described (technically termed "changing face") the *reading* of any object *A* becomes altered by 180°. Whence it follows, that were there an *even* number of Verniers, "changing face" would simply make the opposite Verniers exchange places without the desired alteration of reading being produced. The Vernier should neither press on the limb, nor yet rise above it. In the former case the graduations on the limb must become worn, and since the Verniers are generally minutely unequal in distance from the axis of motion, a space will be created between the longest or the shortest Verniers and the limb, according as the Verniers form an external or internal circle to the limb. The internal Vernier is preferable, because it can be better illuminated and is less liable to become raised above the limb, an evil already alluded to and which creates an uncertainty of reading according as the lens is normally under the eye or otherwise.

The Azimuthal Level.

19. The Azimuthal Level is suspended by two drawing screws working in collars, and it is desirable that the Level should be fixed as high up on these screws as practicable; that is to say, when adjusting the

Level in its place, always raise the required end in preference to lowering the other. For it is evident, that the longer the lever the more liable will the Level be to shake and derangement. Analogous remarks apply to the Level employed in observing vertical angles.

The Clips.

20. The Clips should furnish *points* of contact with their appointed shoulders, not surfaces, and they ought to work antagonistically in the same straight line. When the circumstances existing are contrary to these conditions, the Clips have a tendency to raise or twist the pivots of the transit axis.

The Pivots and Cleats.

21. The Pivots of the transit axis should always be wiped clean before being placed in their *Ys*, for the interposition of grit must necessarily wear them away. The same precaution of course being observed with the *Ys*. The Cleats should neither press on the Pivots, nor yet should there be an intermediate space between the former and latter. In fact there should be contact, without pressure on the one hand, or room for the Pivots to rise on the other. In larger instruments the Cleat sometimes carries a small piece of cork attached to its under-surface, which cork furnishes a point of contact between the Cleat and Pivot.

The Vertical Verniers, Clamp, and Tangent Screw.

22. The Vertical Verniers, Clamp and Tangent Screw are similar in all essentials to those appertaining to the horizontal circle already discussed. It only remains to add, that the plane of the Vertical Verniers should be parallel to the plane of the vertical circle. The segments of the latter admit of depressions and elevations of about 35 and 30 degrees respectively. They are fixed to the Telescope by means of two screws which appear about the imaginary line connecting the zeros of the vertical arcs; and of these screws it is to be noted, that they should never be moved. In the original putting together of the instrument, the plane of the vertical circle was placed perpendicular to the transit axis, and the line joining the zeros on the vertical circle put parallel to the optical axis of the Telescope. At least these conditions were then secured within small limits. There is no object to be attained by opening the screws, while the only probable result obtained will be a general and perhaps permanent derangement of the vertical apparatus. The numerals on the vertical arcs increase from their zero or 0°, both upwards and downwards, thereby furnishing direct readings of elevations as well as of depressions.

Of the Telescope.

23. The Telescope should define sharply and without color,—*i.e.*, the light refracted should be white light. Its object glass is composed of two lenses, the outer being of double convex form and of blue crown glass, the inner lens is concavo-convex, and made of white flint glass. In 7-inch Theodolites these glasses are usually fixtures, but with the larger class of instruments, they can be taken out of their cell on removing a ring which screws against them. The object-glass should always be fairly screwed home in the Telescope, as any rotary motion alters what is termed the 'line of collimation," a technicality to be hereafter explained (1). To the same end, the cap of the object-glass must always be both put on and taken off by the screwing (not unscrewing) motion, since it is usually too tight to be moved without turning it round. The power of a Telescope is measured by the quotient, obtained from dividing the focal length of the object-glass by the focal length of the eye-piece.

The Eye-pieces.

24. There are two Eye-pieces to the Telescope; the shorter one with two lenses, and another with four. The first of these shows objects direct, but since the image formed in the focus of the object-glass is an inverted image, objects seen in the Telescope with this Eye-piece appear inverted; and hence it is called an "inverted eye-piece." By reason of its fewer glasses, it refracts more light, and is the more suitable one to use. The Eye-piece with four lenses is called a "direct eye-piece" for similar reasons. It is the one mentioned at paragraph 4 as not usually

NOTE 1. - The object-glass should also be firmly fixed in its cell.

wanted. The object-glass very rarely requires internal cleaning; indeed, as already implied, it is objectionable to unscrew the object-glass, since doing so deranges the line of collimation. The Eye-piece, however, requires frequent cleaning, chiefly of the outer surface of its outer lens. Glasses should not be opened in damp weather, for the efflorescence which is sometimes found to settle on a lens and dim it, is probably attributable to a neglect of this precaution. It may be readily ascertained which of the two is not clean, the object-glass or the Eye-piece. To this end look into the sky, and at the same time turn the Eye-piece in its cell. If the little specks which appear in the field revolve with this motion, the Eye-piece is at fault. When necessary, select a dry day, and clean the glasses with spirits of wine and a soft handkerchief.

The Diaphragm and how to wire it.

25. The Diaphragm will be found nicked for two systems of wires, one comprising a horizontal and two diagonal wires cutting each other in nearly a common point, and another in which a vertical and a horizontal wire may be employed. The latter is most suitable for luminous signals, which furnish discs for intersection. For ordinary objects, such as poles, brushes, &c., the system of three wires is preferable. To wire the Diaphragm, remove the four small screws which hold the eye-end of the Telescope to the sliding tube. Draw out this end with the eye-piece, and remove three of the four collimating screws. Then turn the fourth a quarter of a revolution, and the Diaphragm will necessarily turn with it and protrude. The latter may now be laid hold of conveniently and removed, and the object in describing this part of the process in detail is, that unless the Diaphragm be similarly handled in replacing it, the chances are that the wires will meet with accident. The wires employed in Theodolites are either silk fibres or spider's lines. The former is the stronger of the two, and wiring may be rapidly effected with it. The spider's web however furnishes the more even wire. Opinions differ on the question of preference between these two, but the silk fibre is probably more suitable to Vernier Instruments (1). In wiring, clean the surface of the Diaphragm and the nicks on it with spirits of wine. The Diaphragm may next be laid on any slightly raised surface. Now select a silk fibre, append a small ball of wax to each end, and fitting the fibre into two opposite nicks, let the balls of wax hang free to tighten the fibre. When the required member of wires are thus placed, fix them to the Diaphragm with drops of laudanum or any other adhesive liquid. A better method of tightening the wires is to open the legs of a hair spring compass sufficiently, first releasing the spring, attach the wires to these opened legs with some wax, and then by drawing the spring, tighten the wire to the required tension. This process may however be overdone, in which case, while avoiding the evil of festooning, a contrary evil will have been incurred; the wire will then be found jagged and as if twisted. A wire should be even edged, of equal thickness, and covering, says Mr. Troughton, two-thirds of the object.

Of the Magnetic Needle.

26. The Magnetic Needle has a positive and a negative end, of which of course the latter flies from the Magnetic Pole. The positive end will generally be found marked. It should be fixed towards the object-end of the Telescope. There is always some little play in the perforations, through which the screws attaching the needle box to the Telescope pass, so that to obtain comparative bearings, the needle box should never be moved intermediately. On the other hand, it is not possible to "change face" with the needle on, since this process brings the box into contact with the nut of the vertical axis. When packing for travelling, the Needle should always be thrown off its centre by means of the small lever provided for this purpose.

Of the Milled-head for adjusting focus.

27. There remains the large Milled-head attached to the side of the Telescope to notice. By means of this screw the adjustment for focus is made. It carries a pinion at its inner extremity, which acting on a rack attached to the sliding tube at the eye-end of the Telescope, pushes out or draws in the

NOTE 1.—That is, to eye-pieces of low powers.

eye-piece. The pinion and rack hardly ever require cleaning, but should this become necessary, the Milled-head may be removed by opening the four little screws which fasten it to the Telescope. As in the case of the tangent screw, the small screw in the centre of this head should be tightened no more than necessary. If this small screw be removed before withdrawing the four little screws above-mentioned, the pinion may drop into the Telescope, and rolling down it to the eye-piece, break the wires.

How to "Change Face."

28. The face of the instrument, it will be observed, stands over Vernier *A*, a condition which is always to be secured when replacing the pivots in their *Ys*. To Change Face signifies to turn the Telescope 180° vertically, that is, on its transit axis. In those instruments which have complete vertical circles, the process comprises a literal following of the above definition; but for obvious reasons a 7-inch requires a somewhat different manipulation. Suppose the instrument to stand at face left, which implies, that standing at the eye-end of the instrument its face falls to the observer's left hand. Now let it be required to Change Face. The manipulation is as follows. Open the cleats and release one of the two clips, the upper azimuthal clamp being free to avoid strains from accidental jerks. Raise the Telescope out of its *Ys*. Hold its object-end with the left hand, and it is useful to remember that this end should never be held uppermost, or any dust within the Telescope will fall on to the wires. Now unclamp the vertical clamp and turn the Verniers 180°, whereby they will change places; clamp, change the Telescope end for end in the hand. Replace in *Ys*, keeping the face over Vernier *A*, and make the released clip pinch. The object and eye ends of the Telescope will thus have exchanged positions, and if as before the observer stand at the latter end, the Face will now fall on his right hand. Before this process was gone through, the instrument was said to be at "Face Left." It now reads "Face Right."

The principle of the Vernier.

29. We may next proceed to the principle of the Vernier. Let it be supposed that the limb is divided to 20′ as is usually the case with 7-inch Theodolites. Take off a distance = 39 such divisions on the vernier plate (which we will suppose for illustration not to be graduated), and thereon divide this distance into 40 parts, numbering every fifth alternate line thus, 5, 10 &c.

then	39	divisions on limb	= 40	divisions on vernier
whence	$\frac{39}{40}$	" "	= 1	"
but	1	" "	= 20′	of arc
∴ 1 division on vernier =	$\frac{39 \times 20'}{40}$	" "	= $19\frac{1}{2}'$	"
And 1 division on limb —	1	Division on vernier	= 30′	"

Generally, if (a) be the arc measure of one division on the limb, and the united distance of n such divisions be taken off on the vernier, then

$$\text{one division on limb} - \text{one division on vernier} = \frac{a}{n+1} \text{ in arc,}$$

wherefore, if the zero or arrow on the Vernier be coincident with the 0° division on the limb, and it be required to increase this reading by 30″, we must turn the Telescope until the first division on the Vernier, counting from its zero, coincides with the 0°20′ line on the limb, when the instrument will evidently read 0°0′30″. So if the zero be pointing to some undefined point on the limb lying between the 27°20′ and 27°40″ lines, while the line on the Vernier coincident with one on the limb is the 17th from the Vernier zero, we have for reading

From the indication of vernier zero ...	...	27-°20′
From coincidence of the vernier 17 × 30′	=	+ 8-30″
Wherefore the instrument reads ...	...	27-28-30

30. The principle and practice of the Vernier will be sufficiently clear from the foregoing; it only remains to notice, that a Vernier can always, when necessary, be read by estimation to half the arc for which it is divided. Thus in a 7-inch, whose limb is graduated to 20 minutes, and when $n = 39$ such divisions, sufficient nicety of reading may be attained to, to estimate such readings as 27° 28′ 15″ or 27° 28′ 45″. In these cases the estimation is made from the *deficiency* of coincidence.

Estimating Reading of Vernier.

31. Further, there will be noticed, that this difference exists between the numbering of the horizontal and the vertical verniers. In both cases the numerals will be found marked at every 5th minute, but in the case of the vertical verniers there appear two sets of numbers, such that the sum of the two numerals at any given line is always = 20. Thus the coincidence may indicate a vernier reading of 7 or 13 of 4 or 16 minutes, &c. The internal numbers, or those nearest the transit axis, are intended for reading elevations. At least this is usually the case. But the observer may readily decide for himself by this rule, the truth of which is apparent. In any given position of the vertical circle, adopt that set of numbers on the vernier which *increase* in the direction *from* the zero on the limb *towards* the zero on the vernier. Thus let the instrument be pointing to an elevation; then 0° on the limb at the object-end of the Telescope will be above the zero on the vernier, and the direction from the former towards the latter is a downwards direction. Whence that set of numbers should be adopted which increases numerically in a downwards progress. Finally, on that segment of the vertical arc towards the object end of the Telescope, there will be seen certain graduations on brass marked as "difference of Hyphothenuse and Base;" which, in other words, means, when the index of this graduation reads the number 2, it is signified that the hypothenusal length at that inclination, minus its corresponding horizontal length, is equal to 2 links per chain.

Of the vertical arcs and verniers.

32. We may now consider the adjustments of the 7-inch Theodolite, which are both included in the following, and performed in the order therein enumerated.

The adjustments.

1. Centering over a given point.
2. Setting the vernier lenses.
3. Obtaining distinct vision of wires.
4. Eliminating parallax, commonly called "finding focus."
5. Setting to zero.
6. Levelling, otherwise making the vertical axis perpendicular to the horizon.
7. Collimating in azimuth.
8. Making the vertical and horizontal wires respectively vertical and horizontal.
9. Setting the level of the vertical arcs to their zero of altitude. To these may be added a tenth, which is however only applicable to those instruments provided with the means of changing the height of one of their pivots.
10. Levelling the transit axis (1).

33. In considering these adjustments, (7) (8) and (10) will not be noticed in the first instance; the intention being to return to these processes so soon as a more intimate acquaintance with the Theodolite has been made.

Prefatory.

34. *Centering.* The Theodolite being placed on its stand, suspend the plummet from the former or the centre of the latter, according as the Theodolite is provided with a hook for the purpose or not. Now move the stand

On centering over a given point.

NOTE 1.—The instrument herein especially commented on, viz., the 7-inch altitude azimuth, is not provided with the means of levelling its transit axis, and hence this adjustment is mentioned last in the enumeration made. In fact, as completing the list, when however the means of doing so exist, the transit axis should be levelled *before* collimating the instrument in azimuth, unless the object observed in collimating be situated exactly in the horizon.

until the point of the plummet is immediately over the given point of observation. The nicety to which this process should be performed, depends firstly on the powers of the instrument, and secondly on the distances of the objects observed generally, in an instrument reading to (n) seconds, it is probable without the limits of accuracy to estimate any angle measured by it as true to $\frac{n''}{2}$; always provided that the Telescope is sufficiently powerful to appreciate the $\angle \frac{n''}{2}$ on its limb. Now, one second of arc at a distance of 43 miles subtends one foot of linear measure nearly. Also in a 7-inch Theodolite $\frac{n}{2} = 15''$. So that if A be the station of observation, and B and C the objects for intersection, such that $AB = AC = 1$ mile (nearly), then we have $\frac{12 \times 1 \times 15''}{43} = 4{\cdot}19$ inches as the limit of uncertainty under the assumed circumstances. But however this may be, the observer should accustom himself to far greater nicety in all his operations, especially when that end may be attained without any serious sacrifice of time. As a general rule, the 7-inch should be centered true to 0·2 of an inch, and this may be effected in half a minute.

Setting the Vernier Lenses.

85. *Setting the Vernier Lenses* is an apparent process. Raise or lower the lens until distinct vision of the Verniers is obtained. Otherwise, place the given Vernier in the focus of its lens. When the Vernier happens to be raised above the limb, the most suitable focus then to be found will evidently bisect the space between the Vernier and limb. In such cases there will unavoidably result what is termed "parallax," an expression to be considered presently in connection with the Telescope.

Prefatory on obtaining distinct vision of the wires, and eliminating parallax.

86. Processes (3) and (4) may be profitably considered conjointly, especially as any *great* change in the focus of the object-glass necessarily produces a sensible difference in the focus of the eye-piece. In the large and more powerful Theodolites, adjustment (4) is rarely if ever required to be altered, and it is to be remembered that such alteration in instruments of all dimensions affects the line of collimation. Owing however to the variability and shortness of distances appertaining to secondary operations, it is ordinarily required to perform adjustment (4) at every station of observation. This however is no reason why the object-glass and eye-piece should be pushed back to their normal position before packing, and since most 7-inch cases will not admit the Telescope as it stands elongated for observation, a suitable recess should be made in the box for this purpose.

The same two adjustments continued.

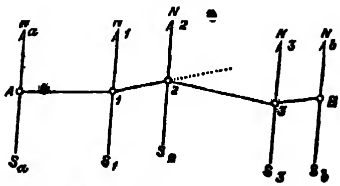
87. To perform (3) turn the Telescope until it looks into the sky, or any other field of vision, devoid of such terrestrial objects as are likely to distract the eye from the wires. Push in or draw out the eye-piece until the wires are most distinctly visible. Now perform (4), and if so doing has deranged (3) readjust the latter finally. The object of the wires is clearly to define a point in the field of vision. Adjustment (4) serves to form the image, refracted by the object-glass, in the plane of these wires; while by means of adjustment (3) the focus of the eye-piece is made to fall in this common plane. In other words, the focus of the eye-piece, the wires and the image refracted through the object-glass, must all lie in the plane of the wires. Wherefore, to perform (4) direct the Telescope to any object which admits of accurate intersection, clamp and intersect. Now, imagining the wires to be fixed, move your head laterally as far as the field will admit, while your eye is intently watching the intersection of the object by the wire. According as the object appears to move, or otherwise, so is it said that there is, or is not, "parallax." In the former case, the image must be formed either between the wires and the eye-piece, or between the wires and the object-glass. The first is distinguished as near, and the second as distant parallax, and the respective adjustments are evidently these. In the first case elongate, by means of the milled-head, the

distance between the wires and object-glass. In the second case, the same distance requires to be shortened, until no parallax is perceptible. As a further assistance in remembering the distinction between near and distant parallax, the following familiar illustration may be useful. Imagine to the east of your position a Church steeple in the distance and a tree in the foreground, on the line drawn from your eye to the former. Let the Church steeple represent the wires. Now if you move to the north, the tree will appear to the south of the steeple; in other words the object will move against the eye as in near parallax. On the other hand, the tree being in the distance while the steeple occupies your foreground, if now you move to the north, so will the tree appear to the north of the steeple, illustrating the case of distant parallax when the object moves with the eye. It is only necessary to remember, that it is the *wires* which represent the fixed object, and the foregoing familiar illustration will always readily show whether the distance between the object-glass and wires should be elongated or diminished. Also, adjustment (3) will be found to vary for different eyes, while (4) should be found suitable to all observers. Adjustment (4) varies rapidly for near objects, owing to the variability in their angles of incidence, which rays from such objects undergo. But so soon as such rays become parallel, or nearly so, the point of no parallax will be found constant for all objects more distantly situated. For instance the point of no parallax for the sun, any planet or star, and for all terrestrial objects 10 or 15 miles distant, will be found to be identical. The condition implied by the technicality "Solar focus" is this, that the rays of light emerging from the given object, and impinging on the object-glass, shall be parallel to one another.

Setting to Zero and the same in connexion with the Needle.

38. Setting to zero requires, that any given point shall read a given reading on the limb, or nearly so. For this purpose, set vernier A to the given reading, unclamp the *lower* clamp and turn the Telescope by the horizontal plate, until the given object is nearly on the wire. Now clamp the lower clamp and intersect with its tangent screw. To perform this process effectually, the instrument should be first roughly levelled. The object to be attained in setting to zero, is to observe the required angles at certain readings and changes of reading, in pursuance of an established system of observation. These readings (in all cases of the left hand point) being technically termed "zero," or origin. Otherwise, in the case of the 7-inch and when carrying on a route survey or traverse, setting to zero combined with the use of the magnetic needle is of considerable utility in checking gross errors of observation. Thus let the following be a route survey:

In which $N_a\,S_a$, N_1S_1, &c., denote the meridians respectively at stations A, 1, &c. Now since the distances involved, A to 1, 1 to 2, &c. = 1 mile or thereabouts, and the 7-inch Theodolite is not capable of measuring angles true to less than 15″ of probable error, it follows, that the convergency of these meridians may be neglected under the circumstances. Whence $N_a\,S_a$, N_1S_1, &c., may be taken parallel to each other. And if N_1 at 1 read A°, and 2 read $A^\circ + a^\circ$, then it is evident, that at 2, if 1 be set to zero $= A^\circ - N_2\,21 = A^\circ + a^\circ - \pi$, the reading of the Magnetic North Pole will remain constant, provided the bearing at 1 of 2 was correctly read. Generally if any forward bearing $= F^\circ$, then while the reading of the Magnetic North Pole remains invariable, the back bearing will always $= F^\circ - \pi$. When this equality is found not to exist, it indicates some error of observation at the preceding station.



On Levelling the Theodolite.

39. *Levelling.* As already indicated, this requirement consists in placing the vertical axis truly perpendicular to the horizon; which may be done thus :—place the Level parallel to any two foot screws, and by suitably turning these latter bring the bubble into the centre of its tube.

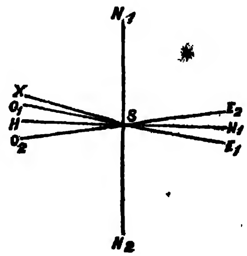
Then turn the Telescope 180° in azimuth, observing that the same direction of motion is adopted on every occasion of azimuthal motion. Supposing the bubble now to occupy a different place from what it did before, move it by means of the two foot screws into the mean of these two places, and it is evident that if the Telescope be further turned 180° in azimuth, *i.e.*, into its original position, the bubble will still continue to occupy that mean place into which it has been moved. This mean place is called the zero of the Level. Next turn the Telescope 90° in azimuth, and by means of only the third and hitherto unused foot screw, move the bubble into the mean place already indicated. The instrument is now level or approximately so, and in the latter case, the foregoing process must be repeated until the bubble continues in the same place, however the Telescope may be made to point. This, mean place should not necessarily be the central one in the tube, but in case the deviation is much more than a sensible quantity, move the bubble as required by means of the two drawing screws which hold its tube. These two processes, *viz.*, that of finding the zero of the Level, and of correcting that zero, have been intentionally kept apart in the above discussion. But they may be readily performed together. Place the Level parallel to any two foot screws, and by means of the latter bring the bubble into a central place. Now turn the Telescope 180° in azimuth. Half the error lies in the foot screws, the other half in the drawing screws before mentioned. The zero of the Level is not constant throughout the day, varying as it does with the temperature. And since the expansion of the liquid contained in the glass tube (spirits of wine) is greater than that of the glass, it follows that the bubble will vary in length inversely with the temperature. So the bubble is shorter at noon than it is of a morning; and from the latter period to the hottest time of the day, its zero will continue to recede towards the centre of the glass tube. For further remarks regarding Levels in general, as also on the determination of the value of a level scale, see Appendix B to "Instructions for Topographical Surveying."

Prefatory.

40. *Setting the Level of the vertical arcs to their zero of altitude* Before considering this adjustment, it is proposed to give a definition of the expression "Line of Collimation."* Thus, the imaginary straight line joining the intersection of the wires and the optical centre of the object-glass, is called the line of collimation.

On setting the Level of the Vertical Arcs to their Zero of Altitude.

41. Now adjustment (9) secures the following conditions. When the bubble of the Vertical Level stands in the centre of its tube (or run), and the Verniers stand at zero, if the Telescope be made to describe an azimuthal circle, then the plane thus generated by the line of collimation should be at right angles to the axis of motion, otherwise the vertical axis. In other words, when the vertical axis is perpendicular to the horizon, and if there be imagined a point X situated exactly in the plane of that horizon, then set the vertical arcs to zero or 0° 0′ 0″ and intersect the object X on the horizontal wire with the *clips*. Now bring the bubble of the Vertical Level into the centre of its run by means of its adjusting screws, and it is evident that adjustment (9) will have been performed. But in reality no such point as the imaginary one, X, exists, whence the process becomes as follows. Let N_1N_2 be the normal to S, HH_1 the horizon, and X any point whose true elevation is $a°$. Level the instrument. Fix the bubble of the vertical circle in the centre of its run by means of its clips, and let the erroneous horizon thus indicated be represented by O_1E_1. Also let the instrument be now standing at face left, then the measured altitude of

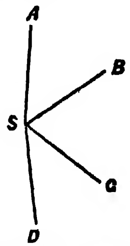


* Collimatio, an aim or level; from collineo, I aim in a straight line.

$X = a^\circ - O_1SH$. Next change face, setting the bubble by its clips as before. Whence if the Telescope be again directed to X, it is evident that the erroneous horizon will be represented by O_2E_2, such that $O_2SH = O_1SH$, Wherefore the measured altitude of X at face right $= a^\circ + O_1SH$, and the mean altitude by face right and left $= \frac{(a^\circ - O_1SH) + (a^\circ + O_1SH)}{2} = a^\circ$ the real altitude. So that, having found the actual elevation, the procedure becomes the same as that already described in the case of an imaginary point situated in the horizon. Thus set the vertical arcs to read an elevation of a°; intersect X by means of the clips, and while maintaining these conditions, bring the bubble of the Level into the centre of its run or glass tube. It is also evident from the foregoing, that provided the position of the level bubble be constant at faces left and right, any error in the assumed horizon will become eliminated in the mean value of the two vertical angles.

On the process of observing Horizontal Angles.

42. We may now proceed to observe with the Theodolite thus adjusted, reserving, as already remarked, adjustments (7), (8), and (10) for subsequent notice. Let it be required to measure on zeros 0° and 180° the angles at S, between A, B, C and D, two measures of each angle being taken at each zero. Here A is the left hand point, and in compliance with the foregoing conditions we will suppose it to have been set to 0°: 1′ on face left. Bring the Telescope up from left to right until it nearly intersects A, clamp and intersect, read and register the verniers, taking the degrees from vernier A. Now examine the intersection, and if found good unclamp and turn towards B, preserving the same direction of motion, clamp, intersect, read, register and examine as before. Similarly proceed to C and then to D, when one round will have been completed. This round will thus have been observed throughout with a similar motion from left to right, and it is required to be noticed, that in such cases when a point is overshot accidentally, the Telescope must be turned back well past the point, before bringing it up again for intersection with the original direction of motion. Now find the mean reading for each intersection, and the differences $B - A$, $C - B$, $D - C$, will be the angles sought. But as two measures are required at each zero, turn the Telescope well past to the right of D, and repeat the round in the order D, C, B, A. In this latter case the motion will be from right to left. In other words, the circumstances of the second round will be contrary to those of the first, and therefore the mean angles of the two rounds are calculated to be free from such errors as may be especially engendered by either circumstances. This completes the two required measures at zero 0°.



Horizontal observations continued.

43. Next change face, which will now become right and proceed as before. In changing face it will be observed, that the place of every vernier for the same intersection has been altered by 180°, and that this result has been obtained without the necessity for relevelling. But here it is to be remarked, that in changing face, the same pivot is always returned into the same Ys. It is true, that were the pivots alone changed, and the Telescope inverted as before, but without any manipulation of the vertical arcs, the readings would be altered by the required angle π, while the face of the instrument would still remain at the observer's left hand. This process is sometimes adopted in route surveys checked by the magnetic needle, for the reason that the face cannot be changed without the objectionable step of removing the needle, and because it is a highly desirable check to measure the required angle at different parts of the limb. But to change pivots, the vertical arcs must be placed over verniers B and C; when the weight of the vertical apparatus, generally without a counterpoise, becomes transferred from one to the other side of the instrument. As a consequence verniers B and C are found difficult if not impossible to read, while the transfer of the

weight above noticed throws the vertical axis out of verticality. Besides, by changing pivots results of error in azimuthal collimation (to be hereafter discussed) are not eliminated in a mean of the two zeros; whereas, by changing face, this elimination is effected. Whence it is undesirable to change pivots at all, and decidedly objectionable if the change be made unintentionally. It is a convenience in observing, that the upper clamp and tangent screws should admit of the lens passing over them, because when this is the case the lens is readily carried round by the shortest route.

The same.

44. Aizmuthal angles should be measured with the vertical clamp free; and it is to be remarked, that if A, B, C and D are at different altitudes, the principle enunciated of retaining similar circumstances throughout any given round, should not be lost sight of, in depressing or elevating the Telescope for the horizontal intersection. That is, if A reads an altitude, B a depression, C another altitude, and so on; then if in intersecting A, the Telescope was raised to the object, so ought it to be depressed below B and raised to it in proceeding to its intersection, and so on. When turning the Telescope horizontally or vertically the force respectively employed should be in those planes; and in the manipulation of the tangent screws, the motion imparted should be truly rotatory without pressure in any direction.

On observing vertical angles.

45. Vertical angles must be observed with the horizontal clamp free, for it will be found that the contrary condition dislevels the instrument. The intersections for these angles are of course made with the horizontal wire, a little on one side of the bisection of the wires, for the sake of clearness, but whichever part of the wire be selected for this purpose, it should constantly be adhered to. The process of observing these $\angle s$ may be thus described, and in so doing it will be useful to imagine that the level is furnished with a scale. Let the instrument be at face left, intersect, note time, read and register verniers and level scale (1), the bubble of the latter being stationary. Now change face, which will thus become face right, and proceed as before. A mean of the two mean values, one at face left and the other at face right, will evidently be free from collimation error (also called index error) as already shown, and in order to find the true observed elevation of the given object, it will only be necessary further to correct this mean result for "level error." See Appendix C and D to "Topographical Instructions." The mean of one observation at face left and one at face right constitutes what is known as a "collimated observation;" it is usual to take at least two such collimated observations on each day of observation.

Of Collimation & Index Error.

46. To find the amount of collimation error, take the difference between the two faces, and halve it. Thus in example 1st, Appendix D "to Instructions for Topographical Surveying," the collimation error is as follows:—

by first collimated observation $\frac{6''\cdot85}{2} = 3''\cdot425$

by second „ „ $\frac{8\cdot20}{2} = 4\cdot10$ Mean $3''\cdot76$

Additive in this example to face left, when the observed vertical angle (at one face only) is a depression.

47. As already remarked, the standard number of vertical $\angle s$ to any given object is two collimated observations, otherwise two pairs, but in those cases when an observer is

NOTE 1.—Theoretically the level scale should be read at the instant of making the intersection for it is required that the conditions existing at that instant should be indicated. But in practice, the movement in the Bubble occasioned by changing face and turning the Instrument horizontally, generally continues for a minute or so after intersection, and hence it is advisable to read the verniers first and let the Bubble have time to steady. In taking the meridional altitudes of the zenith stars at Banog H. S., it was found indispensable that the level scale should be read instantly after observation and before reading the Microscopes.

detained at a station, it is advisable to repeat the angles daily. Vertical observations with instruments which have only segments of the verticle circle, should be taken in rounds; that is to say, if there be objects A,B,C,D, visible at S, the order of observation in rounds would be

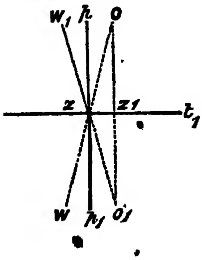
Face Left, A,B,C,D,
Now change face, and observe
Face Right A,B,C,D.

Rigorously speaking, these observations should be taken between the hours of 1½ and 3 P.M. of apparent time, which are about the limiting periods of minimum refraction. Also if at A the object at B be observed at say 1 h. 47 m. P.M., then at B the object at A should be observed at the same hour or nearly so. The reason for this last condition may be stated thus. In computing the angle which subtends the difference of height between A and B, it is assumed that the terrestrial refraction at one station is equal to that at the other; and similarity of circumstances between these reciprocal observations is most likely to produce equality in refraction. The foregoing remarks apply more especially to vertical angles measured with the superior classes of instruments, but they cannot be seriously neglected even in the case of a 7-inch Theodolite; for other reasons excepted, objects may be seen to rise after the period of minimum refraction at the rate of 1 minute of arc in each minute of time, and even more rapidly. But whatever the class of instrument employed, it is obvious that the height of eye and object are essential elements, as without these, the results cannot be reduced to the levels of the stations observed at.

Of Collimating in Azimuth.

48. We may now return to adjustments (7), (8) and (10).

49. A Theodolite is said to be collimated in azimuth when its line of collimation cuts its transit axis or axis of motion at right angles. Thus let $t\,t$ denote the transit axis. Then when the line of collimation (which for shortness sake call c) coincides with the perpendicular to $t\,t_1$ or $p\,p_1$, the instrument is in collimation. And if now it be made to describe a semicircle in its Ys, it will pass through the zenith, *describing* a *great* circle. But if c be represented by OW, then will the semicircle traced out be represented by OO_1, the false zenith being Z_1, while the arc described will be that of a *small* circle. In other words, by changing face, the object end or O will arrive at O_1, while the wires or W will describe a similar *small* semicircle and reach W_1. Whence if any object in the horizon give a horizontal reading at Face Left of $a°$, and then the pivots of the instrument be changed and the Telescope turned sufficiently in azimuth again to intersect the given object, the two readings thus obtained will disagree from each other by OW_1 instead of exactly coinciding.



Wherefore the error in collimation at the horizon will $= \frac{WO_1}{} = Op$.

Methods of collimating enumerated.

50. There are three methods of collimating in azimuth.

1st.—By changing pivots. A process applicable only to small and light instruments.

2nd.—By changing face. An unsuitable method where the verticle circle is not a complete one.

3rd.—By Gaus's method. Which is applicable to all Theodolites.

Collimating by changing Pivots.

51.—*By changing Pivots.* Throw open the cleats and see that the clips are just biting their shoulder and no more. Now intersect azimuthally and note the reading of any fixed object, taking care that the clamps are holding firmly. Next release clips, raise the Telescope gently, and turn its verniers 180° to bring the clips lowermost, change pivots, replace the Telescope without the smallest

knock or violence of any kind, the object-end still pointing towards the fixed object. The success of this process depends on the rigidity of the instrument in azimuth, intermediate to exchanging the pivots. If the Telescope in its second position still intersects the fixed object, the instrument is in collimation, otherwise perform the intersection with the tangent screw and note this second reading. Set the instrument to the mean of these two readings, and then looking into the Telescope, move the diaphragm by its collimating screws until the wires again intersect the object. Repeat the process, until the intersection remains constant on changing pivots, remembering that half the apparent is the real error, and that (with what is called an inverting eye-piece) the diaphragm should be drawn in the same direction which is apparently indicated. In other words, if on reversing pivots, the instrument should prove not to be in adjustment, then set to the mean reading as above explained, and draw the wires *towards* the apparent place of the image.

Continued.

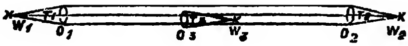
52. It has been recommended in the foregoing that collimation error should be eliminated by finding twice its measure on the limb, and from thence to obtain the reading of the true line of collimation. But the same elimination may also be effected by estimating half the error as it appears in the Telescope, and dispensing with readings.

Collimating by Changing Face.

53. Collimating by changing face is most suitable to weighty instruments with complete vertical circles, in which the face can be changed without the necessity of lifting the pivots out of their *Ys*. In prosecuting this method, intersect and take the reading of any fixed object, change face (not pivots) and intersect and read again. The two readings should disagree by exactly 180°; otherwise correct analogously to the first-mentioned method. It will be observed, that in collimating by changing face, such errors of graduation as may exsit in the divisions of the limb employed, are involved in the process.

Gaus's method of collimating.

54. Gaus's method of collimating is superior to both the foregoing, dispensing as it does alike, with the objectionable necessity of changing pivots in the one process, and the angular measurement, whereby errors of graduation become involved, in the second method. Al[illegible] the adjustment being performed at solar focus, and that focus being the one ordinarily employed in principal operations, this very desirable condition is secured, *viz.*, that the instrument is collimated at a focus which requires no change in actual observation. Whence in collimating large Theodolites by *changing face*, it is essential that the object observed should be fully ten miles away, otherwise the focus must be altered to suit the cases which occur in real work, and the line of collimation be thereby deranged. The reason for the latter derangement is as follows. The sliding and fixed tubes of the Telescopes cannot be fitted to each other so accurately that the line joining their centres shall remain constant when focus is changed. But the first carries the wires and the second the object-glass, wherefore the line joining the former with the optical centre of the latter (*i.e.*, line of collimation) becomes variable if focus be altered. The adjustment performed by Gaus's method requires two auxiliary Telescopes fitted with wires, and it will be found that the Telescopes of the small Theodolites are most suitable for this purpose:



Let W_1 W_2 be the wires and O_1 O_2 the respective object glasses of the two auxiliary Telescopes T_1 and T_2, which set up about 15 feet apart on firm stands. Place the instrument to be collimated (or T_3) halfway between the auxiliaries and in the line joining them. That is to say, when T_1 and T_2 are mutually directed on each other, the line joining the centres of their object-glasses, should pass through the Telescope T_3. Having ascertained a place for T_3 corresponding to the above condition, remove that instrument for the

present. Now set the two auxiliary Telescopes to solar focus as indicated in para. 37. Next turn them to look into each other, and intersect the wires of T_2 (which will appear as if painted on O_2) with T_1, and *vice versa*, until the two Telescopes stand mutually intersecting one another and firmly clamped. It is essential that these mutual intersections should remain unaltered during the after process. Now T_1 and T_2 being both set to solar focus, while their lines of collimation have been placed in the same straight line, it follows that the rays of light emanating from W_1, after being refracted through O_1, are parallel to each other and to the other rays emanating similarly from W_2 and refracted through O_2, while both these sets of rays appertain to the common optical axis W_1 W_2. Whence place T_3, set it likewise to solar focus; intersect W_1 azimuthally, and clamp fairly. Now turn T_3 180° in altitude, and if in adjustment it will intersect W_2, otherwise half the apparent is the real error, which correct by the collimating screws. Repeat the process untilthe error is eliminated. Finally remove T_3, and satisfy yourself that T_1 and T_2 continue mutually to intersect each other.

Making the vertical and horizontal wires, respectively Vertical & Horizontal.

55. Adjustment 9. The angular relation of the horizontal to the perpendicular wire is always defined on the diaphragm, and as they are made to cut each other thereon at right angles, to adjust one wire is to adjust both. For this purpose both the vertical and transit axes (see adjustment 10) must be thoroughly levelled. Now adjust by (say) the vertical wire, thus, intersect any small well defined object, and see if it continues bisected along the wire, when the Telescope is moved in the vertical plane. If otherwise, make the diaphragm revolve until this condition be secured. Similarly, an object bisected by the horizontal wire should continue bisected when the instrument is turned azimuthally. Another method is to suspend a heavy plummet by some fine cord, immersing the former in water to steady it. Now having levelled the vertical and transit axes as before, intersect the cord with the vertical wire, and see if the wire and cord run parallel to each other. If necessary, make the diaphragm revolve through a suitable arc. This last method is not applicable to large theodolites, because it requires that the focus should be altered to the near object presented by the cord.

Prefatory.

56. As already remarked, adjustment 10 can be performed only in those theodolites which are fitted with the means of raising or lowering one of their *Ys*, We will therefore assume, that in this instance, the instrument under manipulation is a 12 or 14 inch. And of smaller theodolites it may be noticed, that their pivots are levelled once for all in their original construction.

The same.

57. A theodolite, fitted as above, will also be found provided with a riding or striding level, so called from its being made to ride astride on the pivots when in use. This level has a smaller level attached to it at right angles, or other contrivance provided, whereby it is "cross-levelled,"—*i.e.*, placed constantly in the same position, with reference to the Co-ordinate which runs at right angles to the transit axis.

How to level the transit axis.

58. To perform adjustment 10, level the theodolite exactly on its azimuthal axis. Place the riding level on the pivots, and by tapping it gently side-ways, bring the bubble of the cross-level into the centre of its run, and when the bubble of the striding level has ceased to move, read and register at what numbers of the level-scale this bubble stands. It will be simpler to take only one end of the bubble into account, *viz.*, that end towards the cross-level, and let it be supposed, that when the foregoing reading was registered, the cross-level stood over that pivot nearest to the face of the instrument. Also for the sake of distinction, call the other pivot, the plain pivot. Now reverse the level end for end,—this is to say, place the cross-level end over the plain pivot. Cross-level as before, read, and register. If the transit axis be level, then will the cross-level end of the bubble read the same number of divisions on the second occasion as it did on the first. But if otherwise, then half the apparent is the real error to be corrected by

the moveable Y. For instance, if the reading on the first occasion was a_1 divisions, and that on the second a_2 divisions, then $a_1 - a_2$ should $= o$ divisions; or $\frac{a_1 - a_2}{2} =$ correction by moveable Y. It will be noticed that during the foregoing process, the instrument must not be moved azimuthally, and that both the vertical and horizontal clamps should be left free.*

Classification of adjustments.

59. We have now completed a consideration of all the adjustments enumerated, and of which adjustments it may be remarked, that if a classification be desired, the following represents the required combinations :

General adjustments	1,2,5,6,9 and 10
Telescopic adjustments	3 and 4
Of the Diaphragm	7 and 8

On the calculation of correction due to imperfect adjustments.

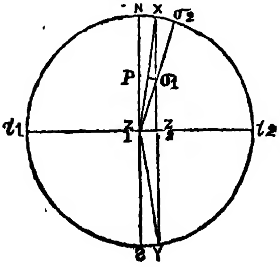
60. Practically and mathematically speaking, there is no adjustment which can be so accurately performed, or which is of so invariable a nature, that the errors due to it should be constantly in a condition of elimination. And it is also to be remembered, that frequent movement of the adjusting screws is a sort of remedy which is worse than the original disease. For so that the existing errors be constant in magnitude during the intervals between relative observations, the corrections due thereto may be readily and accurately calculated. But when once the adjusting screws are worked loose in their sockets, and the error has become of a fluctuating nature, it defies alike cancellment by any system of observation, or elimination by calculated corrections. Wherefore the adjustments being once fairly and firmly performed, they should not be disturbed unless their errors run high. As respects collimation, an error of 5″ at the horizon may be readily not exceeded, and 5 divisions of dislevelment in the transit axis is better left unadjusted. It will be remembered that the foregoing limits represent apparent errors of 10″ in collimation, and 10 divisions of dislevelment in the transit axis. But even supposing these limits to be exceeded, the corrections due may be readily computed as follows.

How to calculate the corrections due to collimation error.

61. And firstly of the computation of corrections due to collimation error.

62. (See Fig. 1.) Let $t_1 t_2$ represent the transit axis, while $N\ S$ denotes the meridian to the given point as also the plane generated by the revolution of the line of collimation when that line cuts $t_1\ t_2$ at right angles. Now disturb the adjustment, so that the telescope will intersect a point X in the horizon instead of N, and when made to revolve in altitude, it will describe the small arc XY. Then $NX =$ observed collimation error at horizon $= p\sigma_1 = Z_1 Z_2 = e$.

Fig. 1.



Z_1 is the true, and Z_2 the false zenith, and of any elevated object σ_1 its $alt = \sigma_1\sigma_2 = A$, and its zenith distance $= Z_1\sigma_1 = Z\ D$. Now the true vertical plane appertaining to the given station of observation and to σ_1 would refer the latter point on the horizon to σ_2, whereas in the assumed state of the adjustments, σ_1 will be referred to X. But X is erroneous by NX, therefore $NX + X\sigma_2 = e + X\sigma_2 = pZ_1\sigma_1 = c$, or correction to reading of the object σ. Therefore in the spherical triangle $p\sigma_1 Z_1$ right angled at p, we have,

* The "Axis Lamp," or lamp for illuminating the wires, always heats and (more or less) raises that pivot on which it shines. Wherefore, for celestial night observations, the transit axis should be examined after the lamp has begun to exercise its full influence.

$$\left.\begin{array}{r} Z_1\sigma_1 = ZD \\ \text{and } p\,\sigma_1 = e \end{array}\right\} \text{ to find } pZ_1\sigma_1$$

$$\text{whence sin. } pZ_1\sigma_1 = \text{sin. } p\sigma_1 \frac{1}{\text{sin. } Z_{.t}}$$

$$\text{or sin. } c = \text{sin. } e \frac{1}{\text{sin. } ZD} = \text{sin. } e \text{ Sec. } A$$

but as c and e are both minute angles

$$c'' = e'' \text{ Sec. A.}$$

Wherein if $A = o^\circ$, then $c'' = e''$. Whence the effect of collimation error is at a minimum, when the point observed is situated in the horizon: also, if the altitude be constant for any two fixed points between which it is desired to measure the horizontal angles, then will the collimation error become eliminated in taking the difference of the two horizontal readings. Further, if the two altitudes be unequal, then will the two angles, one on face left and the other on face right, disagree from each other by twice the difference of effect of collimation error due to their respective altitudes. Wherefore, by finding the mean angle from both faces, the effect of collimation error will become cancelled. Finally, the sign of the *correction* due to any given *reading* from this cause may be determined by the following considerations.

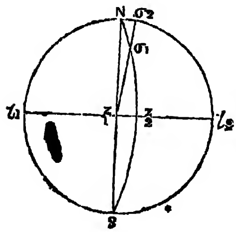
When the reading to any fixed object is greater at Face Left than at Face Right, then will the sign of correction to all readings at Face Left be *minus.* But the foregoing conditions still holding, the observed $\angle$ at Face Left between A and B will be greater than the same observed $\angle$ at Face Right only so long as altitude of $B >$ altitude of A; because, as already shown, the amount of the correction or error varies as the altitude. Also if the distant object observed be not situated in the horizon (see Fig. 1), then it is evident that

$$NX'' = p\sigma_1'' = pZ_1\sigma_1''. \text{ Cos } A.$$

How to calculate the corrections due to dislevelment of transit axis.

63. And secondly of the computation of corrections for dislevelment of transit axis.

64. It has already been shown, that the difference of the readings obtained from the Striding Level before and after changing it end for end on the pivots, measures, in divisions of the level scale, twice the angle Z_1Z_2. Whence $Z_1Z_2 = \varepsilon$ may be found in seconds, since the arc value of 1 division of the level scale is supposed to be known. Now t_1t_2 represents the transit axis as before, and $N\,S$ the plane generated by the line of collimation when the pivots are level. But if t_1 be high, then may that plane become NZ_2S, so that any elevated point σ_1 will be referred to the horizon at N, instead of at σ_2. Wherefore, in the spherical triangle $\sigma_1\,Z_1Z_2$, right angled at Z_2, we have



$$\left.\begin{array}{l} Z_1Z_2 = \varepsilon \\ Z_1\sigma_1 = ZD \end{array}\right\} \text{to find } \left(\frac{\pi}{2} - \sigma_1 Z_1 Z_2\right) = c$$

$$\text{whence cos } \sigma_1\, Z_1\, Z_2 = \tan Z_1\, Z_2 \cot Z_1\, \sigma_1$$

$$\text{or sin. } c = \tan \varepsilon. \tan A$$

and since c and ε are minute angles

$$c'' = \varepsilon''. \tan A$$

wherein A = altitude of σ'. Whence if $A = o^\circ$ then $c'' = o''$; whereby it is proved that the effect of error from dislevelment of the transit axis varies as the altitude becoming evanescent for a point situated in the horizon. Also, as in the case of collimation error the results of the error under comment become eliminated in the following cases:

1. When the observed angle at any one face between fixed objects A and B is such that altitude A = altitude B.

2. And in the mean of the observed angles on both faces, between fixed objects A and B though, altitude of A 7 or $\angle$ alt B.

Further, the sign of the correction may be determined by the following considerations. When that pivot nearest to the face of the instrument is high, the readings of all elevations at face left referred to the horizon will be too low, while depressions similarly referred will produce readings higher than those truly due.

Wherefore if A and B be both Depressions or both Elevations,	Then the observed $\angle$ will be effected by the *difference* of the corrections due to each reading.
But if A be a Depression, and B an Elevation.	Then the observed $\angle$ will be effected by the *sum* of the corrections due to each reading.

And the sign of such corrections to observed *angles* must be determined by considerations analogous to those set forth in discussing the corrections for error in collimation.

The Everest and old fashioned Theodolites briefly contrasted.

65. The reader having considered the foregoing remarks, will probably now be better able to appreciate a brief comparison between Everest's and the old fashioned theodolites.* The former instrument is peculiarly superior in its stability and general simplicity. Thus, the old theodolite has a smaller base, while its centre of gravity stands at a greater height. Now stability varies directly as base and $\frac{1}{\text{height of centre of gravity}}$, whence the advantage in this respect is evidently in favor of Everest's instrument. Again, in the first case, we have four foot-screws, while in the latter there are only three. But in the same circle the base of support offered by the former is to the same presented by the latter as $2 \sin. 45^\circ : r + \cos 60^\circ$ or as $1 : 1 \cdot 06$. Also three points define but one plane, while through four points not in the same plane, no less than five planes may be made to pass. Whence in the old fashioned theodolite, and especially if the foot-screws work unsatisfactorily, there is some difficulty in placing the four points of support, which its foot-screws offer, all in the same plane. The Everest theodolite is also superior in its facilities for changing face, and in the circumstance of a level being directly attached to its verniers, whereby, in observing vertical angles, the surveyor is rendered independent of the azimuthal axis except for the purposes of cross-levelling. In its clamp and tangent screws, in its single plate instead of a double one, in the attachment of its lenses, as well as of its telescope, the Everest theodolite is as superior in theoretical principles, as modern mechanical improvements make it practically superior in elegance and construction. It is *the* pattern of theodolite which, from the 5 to the 1[illegible] inch instrument, is exclusively employed in the Great Trigonometrical Survey of India, and it is also widely adopted in most other surveys.

Vernier Theodolites and Celestial Observations.

66. Vernier Theodolites in the Great Trigonometrical Survey of India are not usually employed for celestial observations unless for the purpose of finding time, by equal altitudes or otherwise; or yet, on other occasions, when extreme accuracy is not required. But the reason why Vernier theodolites are not so employed, is, that the department being provided with far superior reading-microscope instruments, these latter are rightly used in preference to the former. Practically however occasional opportunities occur, when Vernier theodolites *are* used for celestial observations. For instance, at the closing of any extensive secondary operations which may happen necessarily to terminate at a distance from the principal series of triangles. Here the Vernier theodolite may be called upon to verify both azimuth and latitude, the former by observations on a circumpolar star when about its elongations, and the latter by circum-meridional altitudes.

* A sketch of one of the old fashioned Theodolites will be found at page 63 of "Manual of Surveying for India."

67. The problem of observing an azimuth briefly resolves itself into measuring the horizontal angle between any terrestrial mark and the star selected, when the latter is at either its eastern or western elongation. At this instant of time, the ∠ between the star and pole is a quantity which may be readily computed (see Manual of Surveying, pp. 589 to 591), and hence too may be obtained the azimuth or ∠ between the South Pole and Terrestrial mark adopted. The foregoing process however furnishes only one measure of the required angle at each elongation, but for Vernier instruments that one value is probably all that need be observed. When a more rigorous determination of azimuth is required, the process adopted should be in accordance with that detailed at pp. 593 to 598 in the Manual of Surveying for India. Whereby all errors from imperfect adjustments of the instrument, in the place of the star, or the latitude of the station of observation, become eliminated. But though the effects of those errors exist in a single measure of an azimuth observed at only one elongation, they need never be sensible in amount to a Vernier theodolite, unless the instrument is seriously out of adjustment.

Of Azimuth obtained from observations to a circum-polar star.

68. A latitude may be observed either by a single observation on the meridian, or by circum-meridional collimated observations, precisely as in the case of ordinary vertical angles. The latter process, however, requires that the time should be accurately known, and for the former the collimation or index error, as well as the meridian, must be determined.

Of Observed Latitude.

69. In fact the Alt-Azimuth might fitly be named the Universal Instrument, since it may be made to produce any angular measure required, either by direct observation, or indirectly from computation of the same. As such, every surveyor should be thoroughly acquainted with its use, adjustments and individual peculiarities; remembering that truthful measurements depend alike on his skill in observing as on the attention bestowed on his theodolite, and that accuracy is unattainable if patience and a rigorous sense of appreciation be not ever present. To this end too must the surveyor guard against lateral refraction in his horizontal angles. A movement as insidious as it is dangerous, and one which may pass undetected without warning, until exposed by the discordancies in the resulting angles. Lateral refraction is understood to signify a slow oscillation of the object observed; such that, if intersected and watched for some few minutes, it will be observed to move to one side of the wire, then to return to the bisection, and next to perform a similar excursion in the opposite direction. If the wire be so placed that these excursions shall be equal, then it is evident, that that position will represent an intersection. Guard too against hurry and confusion from any cause, bearing in mind that celerity is the result of knowledge, practice, calmness and aptitude combined. Bad angles are worse than none, since the first are absolutely untruthful, while time and patience will always overcome the deficiency. So also discourage self-sufficiency. It is a conceit which rarely comes too late, and there is no more truthful sentiment than that which says, "a little learning is a dangerous thing." Geodetical operations in all their details have long since been brought to a high state of perfection, so that notwithstanding the commendation due to a spirit of research and discovery, see that you do not adopt fictitious ideas on this point, and waste your time and energies in attempting alterations, which, if escaping untruthfulness, are, at the best, probably speaking, but innovations. Follow the broad beaten track, until divested of timidity on the one hand, and of self-sufficiency on the other, you are at least qualified to discriminate between improvement and innovation. Nor have you but a little to learn. As men, though similarly constructed, are yet characterized by special vices and virtues, so theodolites alike in principle and execution have each some peculiar conditions under which they will be found to work more truthfully or otherwise. It is essential that the surveyor should discover these conditions. That he should guard the instrument from sun and rain, from the influence of strong currents of wind blowing on it during observation. That he should pack and unpack it

General.

carefully *himself*, and not by proxy, as is frequently done from laziness and indifference. That he should keep the axis glib, the glasses clean, and the instrument generally in thorough order; and lastly, while in transit from one place to another, the theodolite should be carried by men, with as little concussion and as much care as can be ensured. Observing these precautions, and recording without bias whatever his instrument may indicate, the surveyor *must* arrive at truthful results. Bearing in recollection, that when men's minds are engrossed with microscopic quantities, they are apt to neglect grosser magnitudes; and that to estimate the fractional parts of seconds correctly, while the degrees and minutes are erroneously recorded, is not the way to observe truthful angles. Mistakes in observation occur just as frequently from reading, as from registering, wrongly; and when these two duties are performed by different persons, it is essential that the recorder should repeat distinctly after the observer, the numbers which the latter calls out for registry.

Survey Operations in which Vernier Theodolites are usually employed.

70. Finally the 5 and 7 inch theodolites are chiefly employed in Route Surveys and Secondary Triangulation of an inferior order. Where the secondary operations are of an extensive nature, or other necessity for greater accuracy exists, the theodolite suitable to use is a 12 or 14 inch. The signals in all these instances are, generally speaking, flags, but the 12 or 14 inch is quite capable of appreciating the additional refinement which the employment of luminous signals introduces. Indeed the vertical angles observed with the 14 inch Alt-Azimuth, appear to be equally accurate as those determined by the 24 or 36 inch. So much so, that these two classes of instruments are sometimes conjointly employed, when it becomes desirable to observe vertical angles simultaneously.

In conclusion.

71. In conclusion, it may be some recommendation to the surveyor if he remembers, that the instrument herein commented on is one of the principal means we possess of becoming acquainted with the dimensions and figure of our Planet, as well as with our possessions thereon. Through its agency countries and cities are geographically found, rivers traced, and mountains sketched. It precedes our roads and our railways, and conduces to the construction of our canals, bringing prosperity and happiness where poverty and barrenness before prevailed. In short, it is to the theodolite mainly that we owe our accurate knowledge of the British possessions. It was chiefly with this instrument that the late Lieut.-Colonel Lambton discovered the breadth of the Peninsula, in the parallel of Madras, to have been exaggerated by some miles, and finally it was with the theodolite, that the surveyor, looking from a distance of 133 miles at the summit of Mont Everest, proved its height above the level of the sea to be nearly six English miles.

(Sd.) J. B. N. HENNESSEY,

First Assistant Great Trigonometrical Survey of India.

August, 1859.

MEMORANDUM ON THE USE OF THE PLANE TABLE, FOR TOPOGRAPHICAL PURPOSES.

By CAPT. D. G. ROBINSON, Engineers,

FIRST ASST., SURVEYOR-GENERAL'S DEPT., IN CHARGE TOPOGRAPHICAL SURVEY, BENGAL ESTABT., NO. 1.

1. It will be seen from the following description of the Plane Table, and of the mode of using it, that the same species of results are obtained from it, as regards the plotting of horizontal angles, as are obtained from the Theodolite in the measurement of them,—*i.e.*, in both cases the true azimuthal angle is taken; consequently it is a true triangulating instrument, and a fit adjunct *for filling in the details* of a Trigonometrical Survey, but as in building up triangle on triangle by simple plotting, a large error rapidly accumulates, it should never be used for purposes of extension, or any external work, where great accuracy is required.

2. On a Plane Table the surveyor plots off direct from nature, the angles subtended at his eye, by the various objects he may desire to lay down, or work from, and as his ruler is of full length, his plotting is as accurate as it well can be. He therefore saves much time and avoids all the errors and mistakes to which he would be liable, if he observed his angles with a suitable instrument first, and then plotted them with a protractor.

3. The Plane Table and apparatus, generally used in the Indian Topographical Surveys, are fully described in Appendix (*D*), the table (30 inches by 24 inches) is as large as can be conveniently used, strong and very firm. It answers admirably for accurate survey purposes, but is too heavy for the rough and rapid work of a military reconnoisance. For the latter, a table made of Papier Maché or any suitable light material, 15″×12″, and attached by a ball and socket joint to a light folding tripod stand, would answer better.

4. The ruler is usually about (30) thirty inches long, two (2) inches wide, and (⅓) one-third of an inch thick. The sights are usually about five inches long. The slit of the object-sight should not be less than half an inch in width, and three or four fine holes should be drilled at intervals on the fine cut of the eye-sight. The ends of the ruler should be capped with thin sheet copper, to save the ruler from splitting, and to allow the sights to be screwed on (either temporarily or permanently) more securely and firmly than can be done to the mere wood. Five inches of sight to a thirty-inch ruler gives sufficient command of elevation or depression for general use. When the elevation or depression is more than can be embraced by the sights, the intersection must be made with the assistance of a plummet, suspended in the exact ray, either before the object or behind the eye-sight, as may be required.

The sights of the ruler may be graduated into scales of tangents (to radius length of ruler) or into divisions of so many feet, to enable the surveyor to determine, by the subtended angle, the height of a building or other object, whose distance he knows (either by means of Plane Table or otherwise) or conversely for judging the distance if he knows the height of the object. This may be useful on a reconnoisance, but being only approximate, is of little use to a Topographical Surveyor.

Let us suppose the surveyor in possession of such an apparatus, as that described in Appendix *D.* First he must see that the upper surface of the table is a true plane, and also free from cracks and holes, that the fiducial edges of his ruler are perfectly straight and that the fine cut (slit) of the eye-sight and the wire of the far sight are in the same plane, and that plane perpendicular to the lower plane, or base of the ruler. This can be tested thus. Point the ruler on some small and well defined object, at the distance of 200 or 300 yards or more. Intersect the object with the upper or lower portion of the sights, and moving the eye up and down, see if the slit, the wire and the object still remain in the same line, if they do not, the wire or even the sight must be altered until they do. The perpendicularity may be tested by comparing the sights with a plumb line suspended in front of the board which must be truly level. Next examine the compass. It should play freely, be strongly magnetized, be very sensitive and yet settle quickly.

Having seen that the apparatus is in good order, proceed to mount the board, thus. With a wet sponge thoroughly damp the reverse side of a sheet of good drawing paper, laid flat on a clean table, then roll it up and put it aside until wanted, then thoroughly wash a piece of long cloth, sheeting or some similar material, to get the dirt and starch out of it (the cloth should be large enough to overlap the board by two or three inches every way) let it remain in the water, then spunge the upper surface of the board, and lay on it whilst wet the thinnest paste, then stretch the cloth on the board, as tight as possible, securing the overlap with stiff paste, or glue, to the edge and under surface of the table. Rub the cloth well down on to the board, this will cause it to adhere slightly, and a certain quantity of the thin paste to ooze up through the interstices of the cloth. Then take the paper which by this time will be thoroughly damp, lay it smoothly on the cloth, press it out from the centre with a dry clean towel, and paste the edges down to the cloth with stiff paste. The thin paste which has oozed through will cause the paper to adhere firmly to the cloth, sufficiently to prevent the paper rising, but not so much as to provent its being easily separated when the paper is removed from the board. Great care must be taken not to rub the upper surface of the paper, as, by so doing, its texture is liable to be spoilt and the sizing removed. This may be restored by glazing it with isinglass and alum in the manner recommended in the Manual, Part III, Chapter XIV, page 307. The paper should watched when drying, and, if the centre appear to be drying quicker than the edges, damp it with a sponge.

When the paper and table are thoroughly dry, which will not be for two or three days,* the surveyor may proceed to project the trigonometrical points, the positions of which have been previously determined by careful triangulation with a theodolite. He should first examine the chart of triangulation, and see what points he can get on his table. This is easily done by cutting out a piece of paper to represent the table on the scale of the chart, *i.e.*, if his plane table be 30 inches by 24 inches, the scale of the required survey one mile = one inch, and the chart on the quarter-inch scale, he will prepare a rectangular piece of paper a trifle less than 7½ × 6 inches. This section will contain fifteen minutes of latitude × fifteen of longitude, and his chart will be divided into fifteen minute sections. He lays his piece of paper over the section he is to take up, and shifts it about so as to

* Unless the wood be close grained and very well seasoned, the table will always expand and contract considerably according to the dryness and temperature of the air, and in one direction more than in another. In mounting the table the wood becomes saturated with moisture, which is not expelled for some time after. I therefore prefer keeping the tables mounted several days before the points are projected, and to project then in warm dry weather. Hygrometric expansion or contraction is the bane of a Plane Table Surveyor. By painting, varnishing or by giving some other similar coating to the wood, or by the introduction of some other material in lieu of wood, this evil might probably be ameliorated or eradicated. Oak, Teak and Toon appear to be the best woods for plane tables, Deal and other soft woods imbibe moisture quickly and expand across the grain.

embrace the whole section and as many Trigonometrical sections, and other valuable points as possible (taking care that the section falls well within it), and draws a line all round the edge of the paper. The area enclosed by this line represents on the chart the area proposed to be projected on the plane table.

Thus in Plate XX. facing, on a scale of four miles to one inch, *ABCD*, which includes the required section, say between the Latitudes ($n^\circ : 15'$) and ($n^\circ : 30'$) and Longitude ($m^\circ : 45'$) and ($m^\circ : 60'$), represents the area to be projected on the plane table on a scale of one inch to one mile. The paper has been shifted so as to include the Trigonometrical Stations *I*, *II*, *III*, and *IV*, and the secondary points 1,2,3,4. Lay off with a pair of compasses on your plane table from the corner corresponding to *D*, four times the distance *Dy* along the edge corresponding to *DC*. Similarly lay off from corner corresponding to *A*, four times *Ax*.—draw the line *xy*. This line represents on the plane table the meridian ($m^\circ : 45'$) lay off with compasses four times the distance $y\alpha$, and four times $x\beta$. Then α and β will represent approximately the two western corners of the section. Next with a beam compass take off, from a Gunter's scale, the number of inches corresponding to 15 minutes, difference of latitude between parallels of ($n^\circ : 15'$) and ($n^\circ : 30'$), and lay off that distance, so that the points of the beam compass should be nearly equidistant from the positions (α) and (β) found approximately. These new points define the true position of (α) and (β). Similarly take off with the beam compasses 15 minutes of difference of Longitude at Latitude ($n^\circ : 30'$) and with centre (β), and this radius, draw an arc (γ) also with a distance equal to 15 minutes of difference of Longitude at Latitude ($n^\circ : 15'$), and from centre (α), draw an arc (δ), then with the length of the diagonal for a 15-minute section situated between the same parallels of Latitude, from (α) and (β) as centres, draw other arcs cutting those already drawn in (γ) and (δ)* respectively (γ) and (δ) are the eastern corners of the section. Test them by seeing if $\gamma\delta = \alpha\beta$, and prolong the sides $(\alpha\delta)$, $(\delta\gamma)$, $(\alpha\beta)$, $(\gamma\beta)$ both ways to the edges of the board. The quadrilateral drawn is a 15-minute section; subdivide it into (five) 5-minute sections, and construct diagonal scales for Latitude and Longitude in convenient positions as shewn in Appendix *G*, Colonel Waugh's Topographical Instructions. By means of these scales lay down the different Trigonometrical stations. Next test the positions of the Trigonometrical points† by trying with a beam compass, if the distance between them on the plane table corresponds with the Geodetic distance from the triangle computations. The Trigonometrical Stations having been found correct, lay down the secondary points. If their Latitudes and Longitudes have been computed, project their positions in precisely the same

* The length of the several degrees and half degrees of Latitude and Longitude, and the diagonals of the section corresponding to them for various scales, are tabulated under the letters *m*, *n*, *p*, *q*, in which (*m*) represents the length of Meridional lines, or difference of latitude, (*n*) the lower and (*p*) the upper latitude lines, and (*q*) the diagonal $= m\sqrt{1 + \frac{np}{m^2}}$ *vide* Manual of Surveying for India, Part III, pp. 336 to 347, and Geodetic Tables for use of Great Trigonometrical Survey of India.

† When considering what arrangement of the plane table will be best, after the Trigonometrical Stations, preference should be given to those objects which being visible at a great distance are likely to be most useful, for, as will be seen hereafter, a distant well defined object is of immense use to the surveyor as a point of check, when he requires to find his position by interpolation. To include such valuable points, a small amount of slue may be given, but on no account should the section to be plane tabled be brought so near the edge of the board, as to leave a margin too narrow to include the external points required for the survey of that portion of the work.

manner as before, but if not, by their distances, striking the arcs of intersection with a beam compass. In the latter case every point should have at least three distances. The table is now projected and the surveyor is ready for the field.

On arriving in the field, the surveyor proceeds to some centrical principal Station, and having first seen that the screws of his table and stand are firm, he puts up his table unclamped, as level as possible, and nearly over the centre of the station. He lays whichever fiducial edge he finds most handy (he should make a practice of always using the same edge) so that a line drawn along this edge shall pass exactly through Station *I*, and *II*, on the plane table; Station *I*, being the station he is at, and (*II*,) any other distant, but clearly visible Trigonometrical Station. Holding his ruler firm in this position, he moves his table round (in azimuth) until the eye cut and object hair intersect the real Station *II*, then the straight line connecting Stations *I* and *II* of the plane table is part of the actual straight line between the real Stations *I* and *II*.* He then tightly clamps the table, and examines the intersection and position of the ruler. Finding them correct, he next tests his points. This is done by laying the same fiducial edge so as to intersect plane table Station *I*, and each other plane table point in succession, and seeing if the sights in each instance point exactly to those real points. Or better, reversing the process, he keeps the edges of his ruler close to his plane table position, and intersects the real points with the sight, and sees if the fiducial edge passes through or is exactly parallel to the straight lines connecting his station with the corresponding points on the plane table.† Having satisfied himself that his points are all right, and the table still correctly set, he must proceed to adjust his compass.‡ If the surveyor has the long box compass, he takes it out of its travelling case, and lays one of its long sides coincident with the meridian line nearest his station, and notices its variation. If there be no local attraction, this variation will be pretty constant for all parts of his work, provided he lays the same side of the box on the meridian nearest the point at which he is working. If the compass has no graduated arc, but simply a zero mark, he places the compass either firmly secured in its box, or as before, on any convenient spot on the margin of the table, moves it about until the needle points to zero, and then with a pencil draws lines clearly all round the case, or compass box, so as to be able to replace his compass at pleasure precisely in the identical position which it now occupies.

The surveyor is now in a position to commence filling in, but before entering upon this subject, we will consider the various conditions under which he may have to determine his exact position upon his table.

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* This is not exactly the case, unless Station *I* on the plane table is exactly over the dot of the station. Practically it is, however, correct, as the angular error at Station *II*, subtended by the Station *I*, and the position of the plane table when the distance between them is only 4 or 5 feet is so small as to be far beyond the limits of plotting on a scale of one mile to one inch, and is therefore inappreciable.

† This is usually done by using as a pivot a finger of one hand or a pencil held vertically with its uncut end resting on the paper at a tangent to the station; and with the other hand making the ruler revolve round it so as to intersect each station in succession, in such wise that the fiducial edge of the ruler shall coincide with, or be parallel to, the line joining the station he is at (the eye station) and the plane table station corresponding to the actual station (object station) intersected.

‡ Any kind of a magnetic compass will answer, but the best and most convenient are long box compasses furnished with graduated arcs of about 20 degrees similar to those furnished to Everest's Vernier Theodolite.

Setting a table correctly is simply to clamp it in that position, that any given line on the table passing through your place of observation, shall, if prolonged, pass through, or be parallel to, a corresponding line of the country, so that if you can at once set your meridian line to true north and south, your table is at once correctly set. The compass is a very valuable assistant in obtaining this object, and if the needle points truly, the surveyor at once fixes himself from two known points and checks himself by a third point.

Let it be supposed that having left Station I, he has put up his table at (A), see diagram No. 2.

Now the proper proceeding is that when his table was fixed at Station I, he should, before proceeding to (A), have drawn the ray (I,A) prolonging it, at both ends to the edge of his table,* so that when he comes to Station (A) he has merely to place his ruler, so that the fiducial edge shall coincide with the line (IA), with the eye sight to the (A) end, and to turn the table so that the sights intersect Station I, and clamp it, then he evidently has fixed his table correctly in azimuth. If now he places his pivot at plane table Station (II), and directing his ruler to real Station II, he draws the ray (II,A) its intersection with the line (I,A) is the correct position of (A) upon the table. The correctness of which he tests by drawing rays from IV, III, or any other fixed station, each of which should pass through the same point A. In the diagram No. 2, Stations III and IV are more suitable than II, because the rays from them cut the line (I,a) more nearly at right angles than the ray from Station II does.

It follows from the above that if the positions of II, III, IV, and V are not known, but the distance from (I) to (A) be known, that if you lay off from your scale the distance I,A and fix your table in azimuth by the back ray, you can by drawing rays from A to II, III IV, and V, fix the positions of those stations, provided the rays to them from Station I have previously been drawn.†

It was before observed that the essential point in setting the plane table is that the meridian line nearest to the plane table point, at which the surveyor is working, should be parallel to the actual meridian of that point; in other words that the meridian line of his place should point true north and south, consequently, if the distance from Station (I) to (A) be comparatively short, great care must be taken to set the table *exactly* on the ray (IA), and to ensure this, a flag should be sent on from Station I to Station (A) for the forward ray, and a flag left behind at Station I for the back ray. Suppose in the diagram No. 2 that from want of a flag or other mark, the table is set up by mistake at (a) off the (IA) instead of at (A), then the meridian line of the plane table will take the position sn instead of SN, and the angular error is the angle Nan = angle AIa. Now as $\frac{Aa}{aI}$ may be taken as the measure of this angle, it follows that in proportion as A is nearer to I, so much the more careful must the surveyor be to place his table carefully on the forward ray. There is no necessity for the plane table being placed exactly over the position occupied by the forward flag, all that is necessary is that it be on the ray, *i.e.*, that when the table is set by the back ray, on the back flag, the sights of the ruler point to both flags.

The method just mentioned of fixing the plane table by backward and forward rays has all the advantages of regular triangulation, there is no accumulation of error, and the plotting is as accurate as it possibly can be. This system has also the advantage of requiring fewer points to work with than any other, and it matters not how those points are situated with reference to each other, provided the angles of intersection are not less than 60° (the nearer to right angles the better); but unfortunately it often so happens that the surveyor on arriving at A finds that it is not suitable for his purpose. It may be that A is in the centre of a plateau or in some such position that the view of the ground he wishes to sketch is obstructed: or in passing from (I) to (A) he comes to a

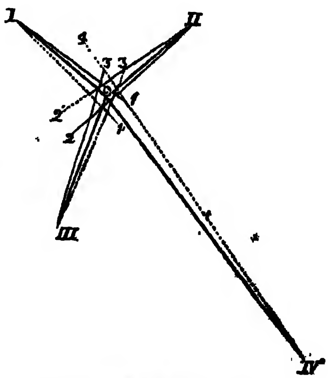
* To give a long line to set by.

† Consequently if you have a base you can build up triangulation by means of a plane table; but however useful this may be for a reconnoissance, it is quite inapplicable to a survey owing to the rapid accumulation of error.

more desirable position, to which no forward ray has been taken, and from which he would like to sketch. He then fixes himself by interpolation. The method of interpolation described in Appendix *A* of Colonel Waugh's Topographical Instructions, is theoretically correct, but is evidently bad in practice. Indeed, under almost all circumstances, fixing by interpolation is objectionable and the evils of the system vary according as the position of the stations fall under the following cases.

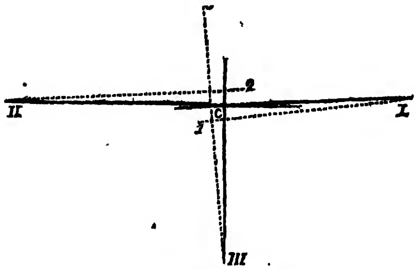
No. I.—The best of all cases is when your position falls exactly in the same straight line with two fixed stations as at *B* or *b* in diagram (see fig. 2), the first between, the second outside, of the Stations *I* and *III*; in this case, move your table until the sights intersect *I* or *III*, if it intersects one it will intersect both—clamp, draw rays from *II* and *IV* and *VI* (the best points for intersection) those rays will cut the straight line *I* and *III* or its prolongation, in the same point (and check each other), *B* in the first case, or *b* in the second, is evidently your position on the table.

The next best condition is when points on all sides are visible from your position A, see former diagram. Put up your table, place the side of your compass to correspond with the nearest meridional line to your position, or if a place has been drawn for it on the table, into that place and turn the table round until the compass stands precisely at the same variation as it did at your starting Station *I*.—Clamp—your table is now fixed approximately in azimuth, put your pivot on any near Trigonometrical point of your table, such as *III*. Point the ruler to *III* and draw the ray, do the same through *VI* and *V*, and if you please through *I*. If your compass be a good one, your table will in all probability be at once set correctly in azimuth, and the rays will then pass through one point; if they do, check by seeing if the ray from the farthest visible point will do so also; if it does you have determined your correct position on the table; but if not, then your table has been set slightly wrong in azimuth, and the angular error must be eliminated. If in the accompanying sketch we suppose the table in the first instance to be set correctly,—*i.e.*, with the meridian nearest to *C* pointing due north, then will all the rays from Station *I*, *II*, *III*, *IV* pass through *C*; but if incorrectly set, then will the rays fall as 1_1 2_2 &c. or as 1_1 2_2 3_3 &c., according as the error in a azimuth is east or west. Now it is evident that the angles formed at the Station *I*, *II*, *III*, and *IV*, by the correct, with the incorrect rays are for the same position of the table always equal, also that when your stations are around you, the figure formed by either set of incorrect rays, inclose the true position, and consequently we obtain the following rule. *When the points by which you are fixing are around you. Your position is within the figure formed by the intersections of the rays and distant from each ray exactly in proportion to the distance of the stations appertaining to that ray from your position.** Estimate *C* to be that point, lay the edge of your ruler coincident with your longest ray (*IV*) *c*, shift the table so as to intersect Station *IV*, clamp and draw fresh rays from *I*, *II* and *III*. These rays should intersect each other in one point which is then your correct position. If they do not, repeat the operation until they do. Each approximation will of course come nearer and nearer to the truth.

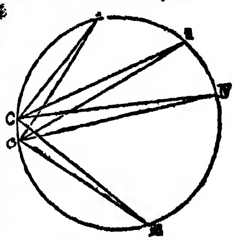


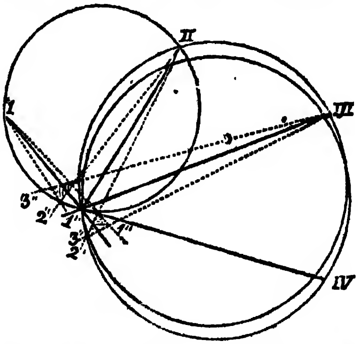
* As the error in Azimuth is the same for all rays, the error in position depends upon the length of the rays. *Ergo*, a surveyor should always fix himself by near points as giving the least errors of position and check himself by far, as shewing most strongly the amount of error to be eliminated.

Again—If, as in the Fig. Station *I* and *II* be nearly opposite each other, and *C* be the correct position of the surveyor, it is evident that the erroneous rays due to the same error in azimuth from *I* and *II* fall on opposite sides of *C*. Consequently if you have only the erroneous rays drawn, you know that the true position of *C* is between I_1 and II_2; and on the same side of III_3 (looking from the Station *III*), as it is if the other rays looking from *I* and *II* respectively. In the figure it falls to the right of I_1 and II_2, therefore it is to the right of III_3. Its distance from those rays will be also as the distance of the stations from it. Estimate accordingly, and having assumed your new position, set your table by it, and the furthest station distinctly visible, and proceed as before.



The fourth, and worst case is when the stations all fall on the same side of the position. It may so happen that the Stations *I*, *II*, *III*, even more stations, and the point *C* are in the circumference of the same circle or very nearly so. When this happens let the surveyor's azimuthal angular error be ever so great, the rays from those stations must intersect in one point, and consequently he cannot detect his error, should there be one. His eye can tell sufficiently nearly if a circle described through *I*, *II*, *III*, would pass through or nearly through *C*, and should such be the case he should on no account whatever attempt to fix himself by those points. Under the best of circumstances his rays must fall, if wrong, something similar to I_1 II_2 III_3 forming a figure on one side of *C*, and there is nothing in that figure to assist him in judging on which side of it *C* should fall. He may obtain his position by judging how a circle passing through *I* and *II*, and the intersection of the rays from those two stations would intersect another circle passing through *II* and *III* or *III* and *IV* and the intersection of their respective rays. (The point of intersection is manifestly the same for all the circles.) He may assume this point as an approximate position for *C*. Let him then set his table by this approximate *C* and his furthest station, and try to fix himself by the near stations, and continue repeating the process until all the rays intersect exactly in one point.*





This last case is manifestly so unsatisfactory that it should never be resorted to except under the greatest necessity. In no case should the surveyor attempt to fix himself by distant points, and he should only sketch such ground from positions so determined as he can get at in no other way.

The following are instances in which case No. 4 are likely to occur, and the following hints may be useful to enable the surveyor to make the best of the difficulty.

* As he approximates nearer to his true position, the figure formed by the intersection of the rays will decrease. And should he pass to the further side of *C*, the figure formed by the intersection of his rays will be inverted.

The most ordinary case is when the surveyor has to descend the side of a hill, in order to see into some hollow, or to sketch some ground not visible from the top. In this case, unless the ground permits of his taking a forward ray, he is without remedy. At another time he will find his view so obstructed by trees covering the whole top of the hill, that his angle of view is very limited at every position he may take up. In this instance, starting from any point near the centre, he should set table by the compass, and take rays to all the points that are visible, then shift a few feet and set his table by the longest of the rays just taken: draw rays to new points that are visible, then shift again, and so on until he is properly fixed, remembering always to fix by long rays, and never to shift from his original starting point, more than is utterly inappreciable on the scale of his survey.

Again, he may be working along the edge of a forest or in a plane below a range of hills where he cannot see any, or perhaps only one, station in the plain besides the stations on the hills, or may be, no plain stations at all. In this case he should regularly traverse by backward and forward rays, with flags, starting from one station and closing on another, fixing himself by rays from stations on his flank, when visible, or when none are visible, by measuring his distance from flag to flag, by chain or perambulator, and laying off those distances with a pair of compasses from a scale on to his table.

He should close his traverse on a Trigonometrical point, and avail himself of every opportunity of check. He should traverse as straight as possible and by long lines so as to reduce to a minimum the accumulation of angular and linear error. If he has a choice, and in the plains he often will have, he should start from a Trigonometrical Station and move in a continuous straight line, until he arrives at a good point of check, then he may run off on a different line, his measurements will then all be from origin, and his linear and angular error will be at a minimum.

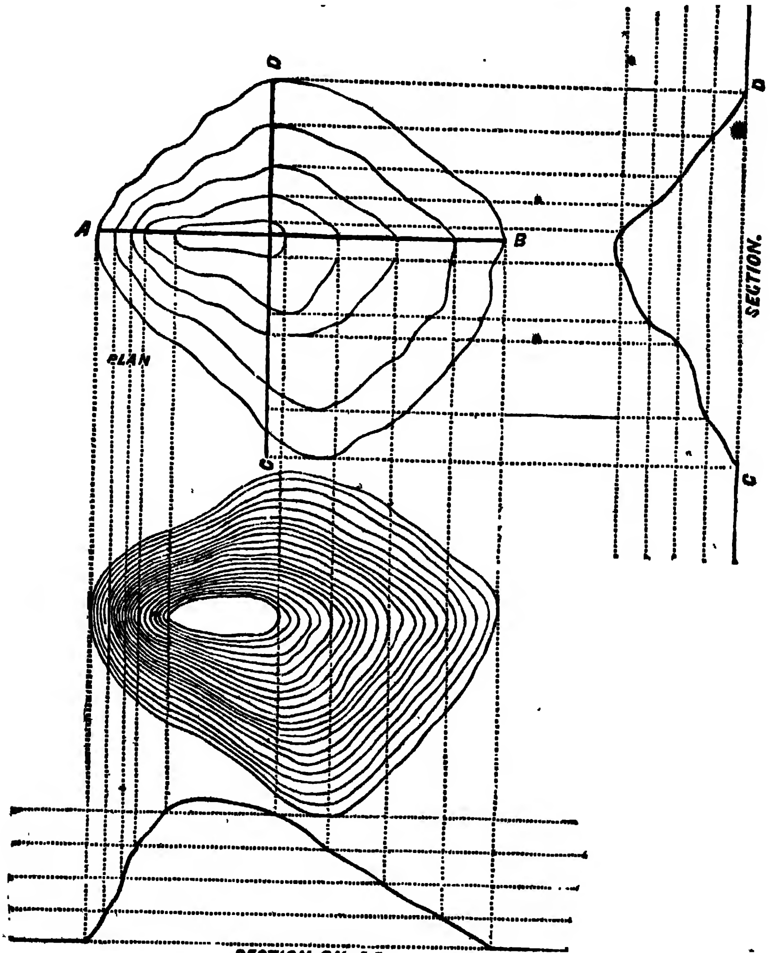
These same triangulating principles which we have described, as guiding the surveyor in determining his own, and in laying down the position of other fixed points, also hold good in filling in the ground. Let us consider this filling in.

The first great rule in sketching ground is to give a proportionate amount of shade for a corresponding steepness of slope. Some writers give a regular scale of shade which is very well in theory, but which, if strictly adhered to in practice, would make the drawing of a map hard, unsightly and illegible. A good surveyor will make this rule his guide, but influenced by a good taste, he will always give to his higher mountains a darker shade than is simply due to the slope, in order to make them appear to stand out from the paper. His high level grounds in the same way will be lighter, and the summit of his high mountains bright white, whilst he will put a flat shade over his low valleys and plains, and suppress all lower features, and this he will do so judiciously that, whilst the general tone of his map is enhanced, he will in no instance destroy its truthfulness. This judicious application of light and shade may be termed the artistic portion of a surveyor's work, and is far easier learnt from a few field lessons than from the clearest written lecture.

Mountainous features may be drawn; *first*, by contours; *secondly*, by eye contours, a modification of the first; *thirdly*, by vertical hatching; *fourthly*, by shading with the brush in Indian ink, or some other suitable tint.

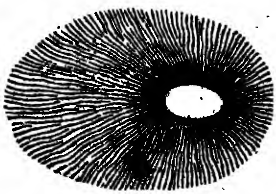
In contouring, regular horizontal lines, at fixed vertical intervals, are traced over the country, and plotted on to the maps. It is a tedious and expensive process, and in the richest country, in the highest state of civilization, is not worth the expense. The accompanying diagram will give some idea of this mode of delineating ground. The contours are supposed to be drawn at certain equal vertical distances, and it will be evident from inspection of the sections that where the hill is steepest the contour lines are closest. These contours at long intervals on a large scale are difficult to read, but if between the lines you interpolate 10, 20, or 15 other lines, you will get a closer and closer approach to regular shading, and it is evident that in proportion as the hill is steep so will this shading be dark or light. Eye contours sometimes called the horizontal system of sketching, is an eye modification of contouring. The style is easy, light, effective, and affords great opportunity

for artistic skill. All that is necessary is that the surveyor when sketching an eye contour should consider, if a person walked horizontally, what lines he would move on, or what routes would he pursue, and his eye contours should approximate the plans of those imaginary lines.

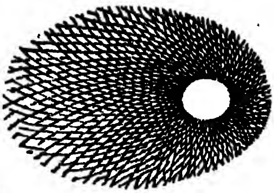


SECTION ON A B.

The vertical system, or hatching, starts by considering the course a volume of water equally disseminated from the top of a hill would naturally pursue, in running down its sides (*Vide* sketch). In this system also it is evident that the steepest sides will have the shorter bases, and the streams will then flow closer to each other than in the more gentle slopes, and thus the different slopes are shaded darker or lighter according as they are steep or gentle. In shading with a brush, the same principles still guide us.



For effect: The hill sides are usually shaded off, from darkest at the top to lightest at bottom, which also generally corresponds with nature, as most mountains are steeper at the summit and ease off near their bases. The great objection to simple shading is the difficulty of shewing all the minor features, clearly and effectively, without overcrowding, and making the whole confused. This is not the case with the simple pen lining. Every line with the pen expresses a feature, and every feature that will shew on the scale can be accurately and easily drawn. But unless the pen work be highly finished and minutely worked up, it is ineffective, and difficult to read. I have therefore introduced into the surveys of which I have had charge a combination of the pen and brush, which includes the advantages and excludes the disadvantages of each system. The ink lining is penned in over the pencil lines executed in the field. The paper is then cleaned, and the relief is obtained by judicious shades of Indian ink or any neutral colour. This is an expeditious, and very effective mode of delineating ground.



It is usual to consider the light to come into the map from the upper left hand or north-west corner, and consequently to shew all parts of buildings, steep banks, and such like objects (which shew no base), with a thick line on the obverse, *i. e.*, *south-east* and *north-east* sides of them.

This arbitrary arrangement gives great effect to the parts of a map to which it is applicable, but is sometimes inconvenient; a river may have both steep or both low banks, or one steep and one high. According to custom, if the bank lies on the north-west side of the watercourse, it ought to be drawn with a thick black line, but if it lies on the south-east side, it ought to have a fine line, *i. e.*, it ought to be drawn in precisely the same way if the bank be low or high, or if there be no bank at all, which is manifestly wrong and inconvenient.

The symbols used to represent Churches, Temples, various Bridges, and other remarkable objects are given in most works on Surveying or Reconnoisance. A very useful table of them adapted to India is given in the "Manual of Surveying for India," Part III, Chapter XIV, page 302.

The following hints on sketching and filling in the ground will be found useful. As soon as the surveyor has set his table at Station *I* and tested his points, he is ready to commence sketching. With this object he draws rays from his station to all the remarkable points, such as peaks, houses, trees, &c., around him, and within a reasonable distance (5 or 6 miles); and estimating the distance assigns an approximate position to them on his plane table; he also draws rays to the junctions and turns of the different watercourses, a[illegible] spurs, knolls, &c., in his immediate vicinity, and sketches in (lightly) the ground by [illegible] contours. This completed he should move off to some distant commanding point (2 miles at least from his first station) set up his table and fix himself (as previously directed). He should then draw rays to all the remarkable objects to which he drew rays from his first station. The intersections of the new and old rays fix the position of all the objects thus laid down, more or less correctly, according as the angles of intersection are good or bad. The positions given by the intersections if not less than 60° may be assumed to be correct, but when the intersections are sharper, only as approximate. These points now become of great assistance; they cover a good area and enable the surveyor to judge pretty correctly the positions of all objects that fall within them or near them. He next draws rays to the spurs, watercourses, and other physical features in his immediate vicinity, and sketches these features lightly in pencil. He then works back towards Station *I*, putting up his table at intervals of from 200 yards to half a mile according as the ground is more or less intricate or difficult to see. From each station he draws rays as before; and fixes the position of the junctions of the watercourses, ends of spurs, knolls, &c., to which he previously drew rays, and he then sketches that part of the ground. In this way he works back past Station *I*, always taking rays to remarkable objects and keeping approximate work in advance of his final work. He should never consider any position determined until it has been te[illegible] by at least three rays intersecting at not less than a right angle. When

a surveyor gets into a position where he cannot fix himself for want of Trigonometrical data, he may use any point which has been laid down by not less than three rays from Trigonometrical points, provided these intersections be at not less than a right angle, or his position does not fall outside the pencil of rays of intersection. To secure a number of such subsidiary points, the surveyor should always work along the ridges before descending into the lower ground. He will also find it much easier to sketch with the sun in his front, for if the sun be behind him, no shadows are thrown on the features he is looking at, all look like one continuous mass; but if he have the sun in front of him, objects stand out in strong light and shade, every ravine and turn of a ravine may be detected at once, and it is far easier to pick out or recognise the prominent points.

He will also find it a great advantage to traverse by zigzag (like triangulation) in circuits through the country when the physical formation permits of it. The blank areas thus circumscribed are always filled in much easier, and the zigzag process affords better intersections than can be obtained by working on straight lines.

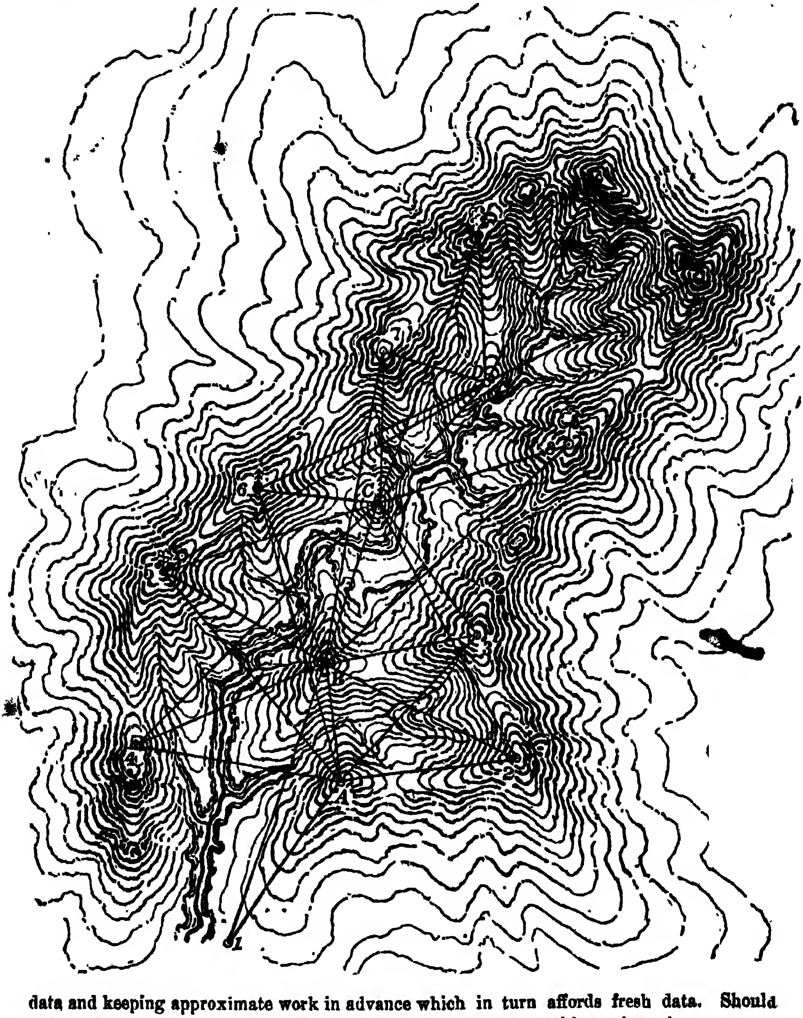
The amount of detail to be shewn will depend upon the scale. On a small scale villages are shewn by circles, on an inch scale they may be laid down by tangents to their edges, the tangents being drawn from so long a distance as to give nearly the correct area of the village, but on the six-inch scale the streets and houses should be shewn. On the one-inch scale, it is also usual to shew, all the different areas, such as cultivation, various kinds of jungle, swamps, &c. The different minor features and the lay of the strata can generally also be shewn, but on the half-inch and quarter-inch scales it will be generally sufficient to shew all ridges and spurs, without reference to their respective slopes. It is a great mistake to attempt to shew too much, as it only tends to confusion. Furthermore many objects, such as precipices, roads, wells, temples, and such like small objects, which would, if drawn to scale, be represented by almost invisible fine lines or points, must be exaggerated on the map, in order that they may draw sufficient attention and receive their true value. Much more might be written to meet the various contingencies of ground and position a surveyor may meet with, but without a few lessons and a little practice in the field, it is almost hopeless to attempt to make a goood topographer, and when once the surveyor has acquired a little practical knowledge, his own wits will always suggest to him the means of overcoming a difficulty.

The foregoing observations appertain to the rigorous filling in of the details of a survey. It often, however, happens that the officer in charge deputes an assistant to make a rough reconnoisance of the country in advance. This reconnoisance becomes a most valuable aid to him in laying out his triangulation, in placing and afterwards in finding the position of any poles he may put up to mark peaks, and other remarkable points likely to be useful to the surveyors employed on the filling in. The Plane Table is very useful for this kind of work. The assistant can advance by a regular series of triangles through the country, laying down the position of all the remarkable objects, with quite sufficient accuracy for the purpose required, and if one chain of triangles passing through the table be measured with a theodolite, computed out and projected as the assistant travels on, a limit of error is fixed, and a really good reconnoisance is made. When the surveyor comes to observe his final angles, he puts up his Plane Table near his instrument, and sets it in the usual manner; he then notes what points he has to observe, and by laying his ruler on each ray in turn, discovers their position. Any surveyor who, looking down from the top of a hill into raviny or flat ground, has had to hunt for poles, or other opaque objects, whose exact position he has not exactly known, will acknowledge the immense comfort of having a good reconnoisance mounted on a Plane Table by his side to guide him in his search.

A very fair reconnoisance may be made by a traveller in a hilly country by keeping himself supplied with points for fixture as he journeys on. Thus from *A*, fix by 1, 2, 3, 4,* and take rays to 5 and 6; at *B*, fix by *A*, 1, 2, 3, 4, and take rays to 5, 6, 7, and 8; at *C* fix by back ray to *B*, by 1, 2, 4, and take rays to 5, 6, 7, 8, 9, 10, &c. The true position of 5, and 6, is now well determined, there being three rays to each; that of 7, and 8, approximately there being only two rays to each. The first two are therefore fit objects for him

* Given points which must have been correctly laid down in the first instance.

to fix by when he comes to *D*, and from that point 7 and 8 are also permanently laid down. Thus the surveyor can proceed from station to station always supplied with points for



data and keeping approximate work in advance which in turn affords fresh data. Should a theodolite be used very fair results should be obtained, but with a prismatic compass or plane table much error is sure to creep in, and it is evident that such a system of reconnoitering is only suitable for a rough preliminary survey, or for military expeditions through a mountainous country where the surveyors cannot leave the line of march.

In conclusion I would observe that whereas, in reconnoitering, a surveyor should avail himself of every facility for making the most of the time and resources at his disposal in a regular systematic survey, he should never deviate from the strict laws of triangulation on which extreme accuracy depends.

SURVEYOR GENERAL'S FIELD OFFICE, } D. G. ROBINSON, *Capt., Engrs.*,
July 12th, 1860. } *In charge Bengal Topographical Survey, No. 1.*

TABLE A.

For Correcting Gunter's Chains of 100 *Links, or* 66 *Feet.*

1 Inch.		2 Inch.		3 Inch.		4 Inch.		5 Inch.		6 Inch.		7 Inch.		8 Inch.		9 Inch.		11 Inch.	
Chains.	Links.	Chains.	Links.	Chains.	Links.	Chains.	Links.	Chains.	Links.	Chains.	Links.	Chains.	Links.	Chains.	Links.	Chains.	Links.	Chains.	Links.
1	0·126	1	0·253	1	0·379	1	0·505	1	0·631	1	0·758	1	0·884	1	1·010	1	1·136	1	1·389
	0·253		0·505		0·758		1·010		1·263		1·515		1·768		2·020		2·272		2·778
	0·379		0·758		1·136		1·515		1·894		2·273		2·652		3·030		3·409		4·167
	0·505		1·010		1·515		2·020		2·525		3·030		3·535		4·040		4·545		5·556
5	0·613	5	1·263	5	1·894	5	2·525	5	3·157	5	3·788	5	4·419	5	5·051	5	5·682	5	6·944
	0·758		1·515		2·273		3·030		3·788		4·545		5·303		6·061		6·818		8·334
	0·884		1·768		2·651		3·535		4·419		5·303		6·187		7·071		7·955		9·722
	1·010		2·020		3·030		4·040		5·050		6·061		7·071		8·081		9·091		11·111
	1·136		2·273		3·409		4·545		5·682		6·818		7·955		9·091		10·227		12·499
10	1·263	10	2·525	10	3·788	10	5·051	10	6·313	10	7·576	10	8·838	10	10·101	10	11·363	10	13·889
	1·389		2·778		4·167		5·556		6·944		8·334		9·722		11·111		12·499		15·278
	1·515		3·030		4·546		6·061		7·576		9·091		10·606		12·121		13·636		16·668
	1·641		3·283		4·924		6·566		8·207		9·859		11·490		13·131		14·772		18·056
	1·768		3·535		5·303		7·071		8·838		10·606		12·373		14·141		15·908		19·444
15	1·894	15	3·788	15	5·682	15	7·576	15	9·470	15	11·363	15	13·257	15	15·151	15	17·045	15	20·833
	2·020		4·040		6·061		8·081		10·101		12·121		14·141		16·161		18·181		22·222
	2·146		4·293		6·439		8·586		10·732		12·879		15·025		17·171		19·317		23·610
	2·272		4·545		6·818		9·091		11·363		13·637		15·909		18·181		20·454		24·999
	2·398		4·798		7·197		9·596		11·995		14·394		16·893		19·191		21·590		26·388
20	2·525	20	5·050	20	7·576	20	10·101	20	12·626	20	15·152	20	17·677	20	20·202	20	22·727	20	27·777
30	3·788	30	7·576	30	11·363	30	15·152	30	18·939	30	22·727	30	26·512	30	30·303	30	34·090	30	41·666
40	5·050	40	10·101	40	15·151	40	20·202	40	25·252	40	30·303	40	35·354	40	40·404	40	45·454	40	55·555
50	6·313	50	12·626	50	18·939	50	25·253	50	31·566	50	37·879	50	44·192	50	50·505	50	56·817	50	69·444
60	7·576	60	15·151	60	22·727	60	30·303	60	37·879	60	45·455	60	53·030	60	60·607	60	68·180	60	83·338
70	8·838	70	17·676	70	26·515	70	35·354	70	44·192	70	53·031	70	61·868	70	70·708	70	79·544	70	97·222
80	10·100	80	20·201	80	30·302	80	40·404	80	50·505	80	60·607	80	70·708	80	80·809	80	90·908	80	111·111

TABLE

For Reducing Chains to

Calculated by

Chains	Decimal parts.	10	20	30	40	50	60	70	80	90	100	110
1	0·0125	0·1375	0·2625	0·3875	0·5125	0·6375	0 7625	0·8875	1·0125	1·1375	1·2625	1·3875
2	·0250	·1500	·2750	·4000	·5250	·6500	·7750	·9000	·0250	·1500	·2750	·4000
3	·0375	·1625	·2875	·4125	·5375	·6625	·7875	·9125	·0375	·1625	·2875	·4125
4	·0500	·1750	·3000	·4250	·5500	·6750	8000	9250	·0500	·1750	·3000	·4250
5	·0625	·1875	·3125	·4375	·5625	·6875	·8125	·9375	·0625	·1875	·3125	·4375
6	·0750	·2000	·3250	·4500	·5750	·7000	·8250	·9500	·0750	·2000	·3250	·4500
7	·0875	·2125	·3375	·4625	·5875	·7125	·8375	·9625	·0875	·2125	·3375	·4625
8	·1000	·2250	·3500	·4750	·6000	·7250	·8500	·9750	·1000	·2250	·3500	[illegible]750
9	·1125	2375	·3625	·4875	·6125	·7375	·8625	9875	·1125	·2375	·3625	[illegible]875
10	·1250	·2500	·3750	·5000	·6250	·7500	·8750	1 0000	·1250	2500	·3750	·5000
	250	260	270	280	290	300	310	320	330	340	350	360
1	3·1375	3 2625	3·3875	3·5125	3·6375	3·7625	3·8875	4 0125	4·1375	4·2625	4·3875	4·5125
2	·1500	·2750	·4000	·5250	·6500	7750	·9000	·0250	1500	·2750	·4000	·5250
3	·1625	·2875	·4125	·5375	·6625	·7875	·9125	·0375	·1625	·2875	·4125	·5375
4	·1750	·3000	·4250	·5500	·6750	·8000	·9250	·0500	·1750	·3000	·4250	·5500
5	·1875	·3125	·4375	·5625	·6875	·8125	·9375	·0625	·1875	·3125	·4375	·5625
6	·2000	·3250	·4500	·5750	·7000	·8250	·9500	·0750	·2000	·3250	·4500	·5750
7	·2125	·3375	·4625	·5875	·7125	·8375	·9625	·0875	·2125	·3375	·4625	·5875
8	·2250	·3500	·4750	·6000	·7250	·8500	·9750	·1000	·2250	·3500	·4750	·6000
9	·2375	·3625	·4875	·6125	·7375	·8625	·9875	·1125	·2375	·3625	·4875	·6125
10	·2500	·3750	·5000	·6250	·7500	·8750	4 0000	·1250	·2500	·3750	·5000	·6250
	500	510	520	530	540	550	560	570	580	590	600	610
1	6·2625	6·3875	6·5125	6·6375	6·7625	6·8875	7·0125	7·1375	7·2625	7·3875	7·5125	[illegible]375
2	·2750	·4000	·5250	·6500	·7750	·9000	·0250	·1500	·2750	·4000	·5250	[illegible]500
3	·2875	·4125	·5375	·6625	·7875	·9125	·0375	·1625	·2875	·4125	·5375	[illegible]25
4	·30[illegible]	·4250	·5500	·6750	·8000	·9250	·0500	·1750	·3000	·4250	·5500	[illegible]50
5	·3125	·4375	·5625	·6875	·8125	·9375	·0625	·1875	·3125	·4375	·5625	[illegible]75
6	·3250	·4500	·5750	·7000	·8250	·9500	·0750	·2000	·3250	·4500	·5750	·7[illegible]00
7	·3375	·4625	·5875	·7125	·8375	·9625	·0875	·2125	·3375	·4625	·5875	·7125
8	·3500	·4750	·6000	·7250	·8500	·9750	·1000	·2250	·3500	·4750	·6000	·7250
9	·3625	·4875	·6125	·7375	·8625	·9875	·1125	·2375	·3625	·4875	·6125	·7875
10	·3750	·5000	·6250	·7500	·8750	7·0000	·1250	·2500	·3750	·5000	·6250	·7500
	750	760	770	780	790	800	810	820	830	840	850	860
1	9·3875	9 5125	9·6375	9·7625	9·8875	10·0125	10·1375	10 2625	10·3875	10·5125	10·6375	10·7625
2	·4000	·5250	·6500	·7750	·9000	·0250	·1500	·2750	·4000	·5250	·6500	·7750
3	·4125	·5375	·6625	·7875	·9125	·0375	·1625	·2875	·4125	·5375	·6625	·7875
4	·4250	·5500	·6750	·8000	·9250	·0500	·1750	·3000	·4250	·5500	·6750	·8000
5	·4375	·5625	·6875	·8125	·9375	·0625	·1875	·3125	·4375	·5625	·6875	·8125
6	·4500	·5750	·7000	·8250	·9500	·0750	·2000	·3250	·4500	·5750	·7000	·8250
7	·4625	·5875	·7125	·8375	·9625	·0875	·2125	·3375	·4625	·5875	·7125	·8375
8	·4750	·6000	·7250	·8500	·9750	·1000	·2250	·3500	·4750	·6000	·7250	·8500
9	·4875	·6125	·7375	8625	·9875	·1125	·2375	·3625	·4875	·6125	·7375	·8625
10	·5000	·6250	·7500	·8750	10·0000	·1250	·2500	·3750	·5000	·6250	·7500	·8750

B.

the Decimal Parts of a Mile.

W. R. M. Graham.

120	130	140	150	160	170	180	190	200	210	220	230	240
1·5125	1·6375	1·7625	1·8875	2·0125	2·1375	2 2625	2·3875	2·5125	2·6375	2·7625	2·8875	3·0125
·5250	·6500	·7750	·9000	·0250	1500	·2750	·4000	·5250	·6500	·7750	·9000	·0250
·5375	·6625	·7875	·9125	·0375	·1625	·2875	·4125	·5375	·6625	·7875	·9125	·0375
·5500	·6750	·8000	·9250	·0500	·1750	·3000	·4250	·5500	·6750	·8000	·9250	·0500
·5625	·6875	·8125	·9375	·0625	·1875	·3125	·4375	·5625	·6875	·8125	·9375	·0625
·5750	·7000	·8250	·9500	·0750	·2000	·3250	·4500	·5750	·7000	·8250	·9500	·0750
·5875	·7125	·8375	·9625	·0875	·2125	·3375	·4625	·5875	·7125	·8375	·9625	·0875
·6000	·7250	·8500	·9750	·1000	·2250	·3500	·4750	·6000	·7250	·8500	·9750	·1000
[illegible]	·7375	·8625	·9875	·1125	·2375	·3625	·4875	·6125	·7375	·8625	·9875	·1125
·6250	·7500	·8750	2·0000	·1250	·2500	·3750	·5000	·6250	·7500	·8750	3·0000	·1250

370	380	390	400	410	420	430	440	450	460	470	480	490
4·6375	4·7625	4·8875	5·0125	5·1375	5·2625	5·3875	5·5125	5·6375	5·7625	5 8875	6·0125	6·1375
·6500	·7750	·9000	·0250	·1500	·2750	·4000	5250	·6500	·7750	·9000	·0250	·1500
·6625	·7875	·9125	·0375	·1625	·2875	·4125	·5375	·6625	·7875	·9125	·0375	·1625
·6750	·8000	·9250	·0500	·1750	·3000	·4250	·5500	·6750	8000	·9250	·0500	·1750
·6875	·8125	·9375	·0625	·1875	·3125	·4375	·5625	·6875	·8125	·9375	·0625	·1875
·7000	·8250	·9500	·0750	·2000	·3250	·4500	·5750	·7000	·8250	·9500	·0750	·2000
·7125	·8375	·9625	·0875	·2125	·3375	·4625	·5875	·7125	·8375	·9625	·0875	·2125
·7250	·8500	·9750	·1000	·2250	·3500	·4750	·6000	·7250	·8500	·9750	·1000	·2250
[illegible]	·8625	·9875	·1125	·2375	·3625	·4875	·6125	·7875	·8625	·9875	·1125	·2375
[illegible]	·8750	5·0000	·1250	·2500	·3750	·5000	·6250	·7500	·8750	6·0000	1250	·2500

620	630	640	650	660	670	680	690	700	710	720	730	740
7·7625	7·8875	8·0125	8·1375	8·2625	8·3875	8·5125	8·6375	8·7625	8·8875	9·0125	9·1375	9·2625
[illegible]	·9000	·0250	·1500	·2750	·4000	·5250	·6500	·7750	·9000	·0250	·1500	·2750
[illegible]	·9125	·0375	·1625	·2875	·4125	·5375	·6625	·7875	·9125	·0375	·1625	·2875
[illegible]	·9250	·0500	·1750	·3000	·4250	·5500	·6750	·8000	·9250	·0500	·1750	·3000
·8125	·9375	·0625	·1875	·3125	·4375	·5625	·6875	8125	·9375	·0625	·1875	·3125
·8250	·9500	·0750	·2000	·3250	·4500	·5750	·7000	·8250	·9500	·0750	·2000	·3250
·8375	·9625	·0875	·2125	·3375	·4625	·5875	·7125	·8375	·9625	·0875	·2125	·3375
·8500	·9750	·1000	·2250	·3500	·4750	·6000	·7250	·8500	·9750	·1000	·2250	·3500
·8625	·9875	·1125	·2375	·3625	·4875	·6125	·7375	·8625	·9875	·1125	·2375	·3625
·8750	8·0000	·1250	·2500	·3750	·5000	·6250	·7500	·8750	9·0000	·1250	·2500	·3750

870	880	890	900	910	920	930	940	950	960	970	980	990
10·8875	11·0125	11·1375	11·2625	11·3875	11·5125	11·6375	11·7625	11·8875	12·0125	12·1375	12·2625	12·3875
·9000	·0250	·1500	·2750	·4000	·5250	·6500	·7750	·9000	·0250	·1500	·2750	·4000
·9125	·0375	·1625	·2875	·4125	·5375	·6625	·7875	·9125	·0375	·1625	·2875	·4125
·9250	·0500	·1750	·3000	·4250	·5500	·6750	·8000	·9250	·0500	·1750	·3000	·4250
·9375	·0625	·1875	·3125	·4375	·5625	·6875	·8125	·9375	·0625	·1875	·3125	·4375
·9500	·0750	·2000	·3250	·4500	·5750	·7000	·8250	·9500	·0750	·2000	·3250	·4500
·9625	·0875	·2125	8375	·4625	·5875	·7125	·8375	·9625	·0875	·2125	·3375	·4625
·9750	·1000	·2250	·3500	·4750	·6000	·7250	·8500	·9750	·1000	·2250	·3500	·4750
·9875	·1125	·2375	·3625	·4875	·6125	·7375	·8625	·9875	·1125	·2375	·3625	·4875
11·0000	·1250	·2500	·3750	·5000	·6250	·7500	·8750	12·0000	·1250	·2500	·3750	·5000

TABLE C.

Showing the Length of a Degree, Minute, and Second, of Latitude and Longitude, for every Degree of a Quadrant, the Compression of the Earth being assumed $\frac{1}{304}$.

Distance from Equator.	Latitude. Lengths in Feet of a Degree.	Latitude. Min.	Latitude. Sec.	Longitude. Degree.	Longitude. Min.	Longitude. Sec.	Distance from Equator.	Latitude. Lengths in Feet of a Degree.	Latitude. Min.	Latitude. Sec.	Longitude. Degree.	Longitude. Min.	Longitude. Sec.
0°	362759	6046·0	100·76	365147	6085·8	101·43	45°	364547	6075·8	101 26	258623	4310·4	71·84
1	362761	6046·0	100 76	365091	6084·8	101·41	46	364610	6076 8	101·27	254084	4234 7	70·58
2	362764	6046 1	100·77	364925	6082·1	101·37	47	364673	6077·9	101 29	249467	4157 8	69·30
3	362769	6046·2	100·77	364649	6077·5	101·29	48	364735	6078·9	101·31	244744	4079·1	[illegible]
4	362776	6046·4	100 77	364263	6071·0	101·18	49	364797	6079·9	101·32	240007	4000·1	[illegible]
5	362785	6046 4	100·77	363767	6062·8	101·05	50	364859	6081·0	101·34	235166	3919·4	65·32
6	362796	6046·6	100 77	363161	6052·7	100 88	51	364920	6082·0	101·36	230252	3837·5	63·96
7	362810	6046·8	100·77	362445	6040·7	100·68	52	[illegible]	6083·0	101·38	225267	3754·4	62·57
8	362826	6047·1	100·78	361619	6027·0	100 45	53	365042	6084·0	101·40	220213	3670·2	61 17
9	362844	6047·4	100·78	360683	6011·4	100·19	54	365102	6085·0	101·41	215091	3584 8	59·75
10	362864	6047 7	100·79	359637	5994·0	99 90	55	365161	6086·0	101·42	209903	3498·4	58·31
11	362886	6048·1	100·79	358480	5974·7	99·58	56	365219	6087·0	101·44	203650	3394·2	56·57
12	362910	6048 5	100 80	357217	5953·6	99·23	57	365276	6087·9	101·46	198334	3305·6	55·09
13	362937	6048·9	100·81	355846	5930 8	98·85	58	365332	6088 9	101·48	192957	3215·9	53·60
14	362966	6049·4	100·82	354368	5906·1	98·44	59	365387	6089 8	101 50	187520	3125·3	52 09
15	362997	6049·9	100·83	352782	5879·7	97 99	60	365441	6090·7	101·52	183025	3050·4	50·84
16	363029	6050·5	100·84	351089	5851·5	97·53	61	365495	6091·6	101·53	177473	2957 9	49·30
17	363063	6051·0	100·85	349290	5821·5	97·02	62	365548	6092·5	101·55	171866	2864 4	47 74
18	363099	6051·6	100·86	347385	5789·7	96·50	63	365599	6093·3	101·56	166206	2770·1	46·17
19	363137	6052·3	100·87	345374	5756·2	95·94	64	365649	6094·1	101·57	160495	[illegible]	[illegible]
20	363177	6052 9	100·88	343258	5721·0	95·35	65	365697	6094 9	101·58	154736	2578·9	[illegible]
21	363219	6053 6	100·89	341038	5684·0	94·73	66	365743	6095·7	101·59	148929	2432·1	41·37
22	363262	6054·4	100·91	338715	5645·2	94·09	67	365788	6096 5	.01 60	143076	2384 6	39·74
23	363306	6055·1	100·92	336289	5604·8	93·41	68	365832	6097 2	101·61	137178	2286·3	38·10
24	363351	6055 8	100·93	333760	5562·7	92·71	69	365875	6097·9	101·63	131236	2187 3	36 45
25	363397	6056 6	100·94	331130	5518·8	91·98	70	365917	6098·6	101·64	125252	2087·5	[illegible]
26	363445	6057·4	100·96	328400	5473·3	91·22	71	365957	6099·3	101·65	119229	1987·1	[illegible]
27	363495	6058·2	100·97	325570	5426·2	90·44	72	365995	6099·9	101·66	113171	1886·2	[illegible]
28	363546	6059 1	100·98	322641	5377·3	89·62	73	366032	6100 5	101·67	107079	1784·6	[illegible]
29	363599	6060·0	100·99	319613	5326 9	88·78	74	366065	6101·1	101 68	100954	1682·6	[illegible]
30	363653	6060·9	101·01	316487	5274·8	87·91	75	366097	6101·6	101 69	94798	1580·0	26·33
31	363707	6061·8	101·02	313265	5221·1	87·02	76	366128	6102·1	101 71	88618	1476·9	24·61
32	363762	6062 7	101·03	309948	5165·8	86·10	77	366157	6102·6	101·71	82400	1373·3	22·89
33	363818	6063 6	101·05	306537	5108·9	85·15	78	366184	6103·1	101·72	76162	1269·4	21·16
34	363875	6064 6	101·07	303032	5050·5	84·17	79	366208	6103·5	101·72	69900	1165·0	19·42
35	363933	6065·5	101·09	299435	4990·6	83·18	80	366230	6103·8	101·73	63616	1060·3	17·67
36	363992	6066·5	101·10	295746	4929·1	82·15	81	366250	6104·2	101·73	57310	955·2	15·92
37	364052	6067·5	101·11	291966	4866·1	81·10	82	366268	6104·5	101·74	50986	849·8	14·16
38	364113	6068·5	101·13	288098	4801·6	80·03	83	366284	6104 7	101·74	44646	744·1	12·40
39	364174	6069·6	101·15	284142	4735·7	78·93	84	366298	6105·0	101·75	38293	638·2	10·64
40	364235	6070·6	101·17	280098	4668·3	77·80	85	366309	6105·1	101·75	31929	532·1	8·87
41	364297	6071·6	101·19	275969	4599·5	76·66	86	366318	6105·3	101·75	25555	426·0	7·10
42	364359	6072 6	101·21	271756	4529·3	75 49	87	366325	6105·4	101·75	19173	319·5	5·33
43	364421	6073 7	101·22	267460	4457·7	74·29	88	366330	6105·5	101·76	12785	213·1	3·55
44	364484	6074·7	101·24	263082	4384·7	73·06	89	366333	6105·6	101·76	[illegible]	106·5	1·78
45	364547	6075·8	101·26	258623	4310·4	71·84	90	366335	6105·6	101 76	0	0	0

NOTE.—The degrees of latitude are calculated for the latitudes of their middle points.

TABLE D.

For Converting Chains and Links into Feet and Decimals of Feet.

Links.	0 Chain.	1 Chain.	2 Chains.	3 Chains.	4 Chains.	5 Chains.	6 Chains.	7 Chains.	8 Chains.	9 Chains.	Dec. of Feet.	Links.	0 Chain	1 Chain.	2 Chains.	3 Chains.	4 Chains.	5 Chains.	6 Chains.	7 Chains.	8 Chains.	9 Chains.	Dec. of Feet.
	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.			ft.	ft.	ft.	ft	ft.	ft.	ft.	ft.	ft.	ft.	
0	0	66	132	198	264	330	396	462	528	594	00	50	33	99	165	231	297	363	429	495	561	627	·00
1	0	66	132	198	264	330	396	462	528	594	·66	51	33	99	165	231	297	363	429	495	561	627	·66
2	1	67	133	199	265	331	397	463	529	595	32	52	34	100	166	232	298	364	430	496	562	628	32
3	1	67	133	199	265	331	397	463	529	595	·98	53	34	100	166	232	298	364	430	496	562	628	·98
4	2	68	134	200	266	332	398	464	530	596	64	54	35	101	167	233	299	365	431	497	563	629	·64
5	3	69	135	201	267	333	399	465	531	597	·30	55	36	102	168	234	300	366	432	498	564	630	·30
6	[illegible]	69	135	201	267	333	399	465	531	597	·96	56	36	102	168	234	300	366	432	498	564	630	·96
7	4	70	136	202	268	334	400	466	532	598	·62	57	37	103	169	235	301	367	433	499	565	631	·62
8	5	71	137	203	269	335	401	467	533	599	·28	58	38	104	170	236	302	368	434	500	566	632	·28
9	5	71	138	203	269	335	401	467	533	599	24	59	38	104	170	236	302	368	434	500	566	632	·94
10	6	72	139	204	270	336	402	468	[illegible]	600	·60	60	39	105	171	237	303	369	435	501	567	633	·60
11	7	73	139	205	271	337	403	469	535	601	·26	61	40	106	172	238	304	370	436	502	568	634	·26
12	7	73	140	205	271	337	403	469	535	601	·92	62	40	106	172	238	304	370	436	502	568	634	·92
13	8	74	141	206	272	338	404	470	536	602	·58	63	41	107	173	239	305	371	437	503	569	635	·58
14	9	75	141	207	273	339	405	471	537	603	24	64	42	108	174	240	306	372	438	504	570	636	·24
15	9	75	142	207	273	339	405	471	537	603	90	65	42	108	174	240	306	372	438	504	570	636	·90
16	10	76	·143	208	274	340	406	472	538	604	56	66	43	109	175	241	307	373	439	505	571	637	·56
17	11	77	143	209	275	341	407	473	539	605	·22	67	44	110	176	242	308	374	440	506	572	638	·22
18	11	77	144	209	275	341	407	473	539	605	·88	68	44	110	176	242	308	374	440	506	572	638	·88
19	12	78	145	210	276	342	408	474	540	[illegible]	54	69	45	111	177	243	309	375	441	507	573	639	·54
20	13	79	145	211	277	343	409	475	541	607	·20	70	46	112	178	244	310	376	441	508	574	640	·20
21	[illegible]	[illegible]	146	211	277	343	409	475	541	607	86	71	46	112	178	244	310	376	442	508	574	640	·86
[illegible]	[illegible]	80	147	212	278	344	410	476	542	608	52	72	47	113	179	245	311	377	443	509	575	641	·52
23	15	81	147	213	279	345	411	477	543	609	·18	73	48	114	180	246	312	378	444	510	576	642	·18
24	15	81	148	213	279	345	411	477	543	609	84	74	48	114	180	246	312	378	444	510	576	642	·84
25	16	82	149	214	280	346	412	478	544	610	50	75	49	115	181	247	313	379	445	511	577	643	·50
26	17	83	149	215	281	347	413	479	545	611	16	76	50	116	182	248	314	380	446	512	578	644	·16
27	[illegible]	[illegible]	150	215	281	347	413	479	545	611	82	77	50	116	182	248	314	380	446	512	578	644	·82
[illegible]	[illegible]	[illegible]	151	216	282	348	414	480	546	612	·48	78	51	117	183	249	315	381	447	513	579	645	·48
[illegible]	[illegible]	85	151	217	283	349	415	481	547	613	14	79	52	118	184	250	316	382	448	514	580	646	·14
[illegible]	19	85	152	217	283	349	415	481	547	613	·80	80	52	118	184	250	316	382	448	514	580	646	·80
[illegible]	20	86	153	218	284	350	416	482	548	614	·46	81	53	119	185	251	317	383	449	515	581	647	·46
32	21	87	153	219	285	351	417	483	549	615	·12	82	54	120	186	252	318	384	450	516	582	648	·12
33	21	87	154	219	285	351	417	483	549	615	·78	83	54	120	186	252	318	384	450	516	582	648	·78
34	22	88	155	220	286	352	418	484	550	616	·44	84	55	121	187	253	319	385	451	517	583	649	44
35	23	89	155	221	287	353	419	485	551	617	·10	85	56	122	188	254	320	386	452	518	584	650	·10
36	23	89	156	221	287	353	419	485	551	617	·76	86	56	122	188	254	320	386	452	518	584	650	·76
37	24	90	157	222	288	354	420	486	552	618	42	87	57	123	189	255	321	387	453	519	585	651	·42
38	25	91	157	223	289	355	421	487	553	619	08	88	58	124	190	256	222	388	454	520	586	652	·08
39	25	91	158	223	289	355	421	487	553	619	·74	89	58	124	190	256	322	388	454	520	586	652	·74
40	26	92	159	224	290	356	422	488	554	620	·40	90	59	125	191	257	323	389	455	521	587	653	·40
41	27	93	159	225	291	357	423	489	555	621	·06	91	60	126	192	258	324	390	456	522	588	654	·06
42	27	93	160	225	291	357	423	489	555	621	·72	92	60	126	192	258	324	390	456	522	588	654	·72
43	28	94	161	226	292	358	424	490	556	622	·38	93	61	127	193	259	325	391	457	523	589	655	·38
44	29	95	161	227	293	359	425	491	557	623	04	94	62	128	194	260	326	392	458	524	590	656	·04
45	29	95	162	227	293	359	425	491	557	623	·70	95	62	128	194	260	326	392	458	524	590	656	·70
46	30	96	163	228	294	360	426	492	558	624	·36	96	63	129	195	[illegible]	327	393	459	525	591	657	·36
47	31	97	163	229	295	361	427	493	559	625	·02	97	64	130	196	262	328	394	460	526	592	658	·02
48	31	97	164	229	295	361	427	[illegible]	559	625	·68	98	64	130	196	262	328	394	460	526	592	658	·68
49	32	98	165	230	296	362	428	494	560	626	·34	99	65	131	197	263	329	395	461	527	593	659	·34
50	33	99	165	231	297	363	429	495	561	627	·00	100	66	132	198	264	330	396	462	528	594	660	·00

TABLE E.

Atmospherical Refractions.

App. Altitude.	Refr. B. 30. Th. 50°.	Diff. for 1′ Alt.	Diff. for + 1 B.	Diff. for — 1° Fa.	App. Altitude.	Refr. B. 30. Th. 50°.	Diff. for 1′ Alt.	Diff. for + 1 B.	Diff. for — 1° Fa.
D.M.	M. S.	S.	S.	S.	D.M.	M. S.	S.	S.	S.
0° 0	33 51	11·7	74	8·1	4 0	11 52	2·2	24·1	1 70
5	32 53	11·3	71	7 6	10	11 30	2·1	23·4	1·64
10	31 58	10 9	69	7 3	20	11 10	2·0	23 7	1·58
15	31 5	10·5	67	7 0	30	10 50	1·9	22·0	1·53
20	30 13	10·1	65	6 7	40	10 32	1·8	21·3	1·48
25	29 24	9·7	63	6 4	50	10 15	1·7	20 7	1·43
30	28 37	9·4	61	6·1	5° 0	9 58	1 6	20·1	1·38
35	27 51	9·0	59	5 9	10	9 42	1 5	19·6	[illegible]
40	27 6	8·7	58	5·6	20	9 27	1·5	19·1	1·30
45	26 24	8·4	56	5 4	30	9 11	1·4	18 6	1·26
50	25 43	8·0	55	5·1	40	8 58	1 3	18 1	1·22
55	25 3	7·7	53	4·9	50	8 45	1·3	17·6	1·19
1° 0	24 25	7·4	52	4 7	6° 0	8 32	1 2	17 2	1·15
5	23 48	7·1	50	4·6	10	8 20	1·2	16·8	1·11
10	23 13	6·9	49	4·5	20	8 9	1·1	16 4	1·09
15	22 40	6·6	48	4·4	30	7 58	1 1	16·0	1·06
20	22 8	6·3	46	4·2	40	7 47	1 0	15·7	1·03
25	21 37	6·1	45	4·0	50	7 37	1·0	15·3	1·00
30	21 7	5·9	44	3·9	7° 0	7 27	1·0	15 0	0·98
35	20 38	5 7	43	3·8	10	7 17	·9	14·6	·95
40	20 10	5·5	42	3 6	20	7 8	·9	14·3	·93
45	19 43	5·3	40	3·5	30	6 59	·8	14·1	·91
50	19 17	5·1	39	3·4	40	6 51	·8	13·8	[illegible]
55	18 52	4·9	39	3·3	50	6 43	·8	13·5	·87
2° 0	18 29	4·8	38	3·2	8° 0	6 35	·7	13 3	0·85
5	18 5	4·6	37	3·1	10	6 28	·7	13 1	·83
10	17 43	4·4	36	3 0	20	6 21	·7	12·8	[illegible]
15	17 21	4 3	36	2 9	30	6 14	·7	12 6	[illegible]
20	17 0	4 1	35	2 8	40	6 7	·7	12 3	[illegible]
25	1[illegible] 40	4·0	34	2·8	50	6 0	·6	12·1	[illegible]
30	16 21	3·9	33	2·7	9° 0	5 54	·6	11·9	0·76
35	16 2	3·7	33	2·7	10	5 47	·6	11·7	·74
40	15 43	3·6	32	2·6	20	5 41	·6	11·5	·73
45	15 25	3 5	32	2·5	30	5 36	·6	11·3	·71
50	15 8	3·4	31	2·4	40	5 30	·5	11·1	·71
55	14 51	3·3	30	2·3	50	5 25	·5	11·0	·70
3° 0	14 35	3·2	30	2·3	10 0	5 20	·5	10 8	0·69
5	14 19	3·1	29	2·2	10	5 15	·5	10·6	·67
10	14 4	3·0	29	2·2	20	5 10	·5	10·4	·65
15	13 50	2 9	28	2·1	30	5 5	·5	10 2	·64
20	13 35	2·8	28	2·1	40	5 0	·5	10·1	·63
25	13 21	2·7	27	2 0	50	4 56	·4	9·9	·62
30	13 7	2 7	27	2·0	11° 0	4 51	·4	9·8	0·60
35	12 53	2·6	26	2·0	10	4 47	·4	9 6	·59
40	12 41	2·5	26	1·9	20	4 43	·4	9·5	·58
45	12 28	2·4	25	1 9	30	4 39	·4	9 4	·57
50	12 16	2·4	25	1·9	40	4 35	·4	9·2	·56
55	12 3	2·3	25	1 8	50	4 31	·4	9·1	·55

TABLE E.—(*Continued.*)

Atmospherical Refractions.

App. Altitude.	Refr. B. 30 Th. 50°	Diff. for 1′ Alt.	Diff. for +1° B.	Diff. for −1° Fa.
D.M. °	M. S.	S.	S.	S.
12. 0	4 28·1	·38	9·00	·556
10	4 24·4	·37	8·86	·548
20	4 20·8	·36	8·74	·541
30	4 17·3	·35	8·63	·538
40	4 13·9	·33	8 51	·524
50	4 10·7	·32	8·41	·517
13. 0	4 7·5	·31	8·30	·509
10	4 4·4	·31	8·20	·503
20	4 1·4	·30	8·10	·496
30	3 58·4	·30	8·00	·490
40	3 55·5	·29	7·89	·482
50	3 52·6	·29	7·79	·476
14. 0	3 49 9	·28	7·70	·469
10	3 47·1	·28	7 61	·464
20	3 44·4	·27	7·52	·458
30	3 41·8	·26	7·43	·453
40	3 39 2	·26	7·34	·448
50	3 36·7	·25	7·26	·444
15 0	3 34 3	·24	7·18	·439
30	3 27·3	·22	6·95	·424
16. 0	3 20·6	·21	6·73	·411
30	3 14·4	·20	6·51	·399
[illegible]. 0	3 8·5	·19	6·31	·386
30	3 2·9	·18	6·12	·374
18. 0	2 57·6	·17	5·98	·362
19. 0	2 47·7	·16	5·61	·340
20	2 38·7	·15	5·31	·322
21	2 30 5	·13	5·04	·305
[illegible]	2 23 2	·12	4·79	·290
[illegible]	2 16·5	·11	4 57	·276
24	2 10·1	·10	4·35	·264
25	2 4·2	·09	4·16	·252
26	1 58·8	09	3·97	·241
27	1 53 8	·08	3·81	·230
28	1 49·1	·08	3·65	·219
29	1 44·7	·07	3·50	·209
30	1 40·5	·07	3·36	·201
31	1 36 6	·06	3 23	·193
32	1 33·0	·06	3·11	·186
33	1 29·5	·06	2·99	·179
34	1 26·1	·05	2·88	·173
35	1 23·0	·05	2·78	·167
36	1 20·0	·05	2·68	·161
37	1 17·1	·05	2·58	·155
38	1 14 4	·05	2·49	·149
39	1 11·8	·04	2·40	·144
40	1 9·3	·04	2·32	·139
41	1 6 9	·04	2·24	·134

App. Altitude.	Refr. B. 30 Th. 50°	Diff. for 1′ Alt.	Diff. for +1° B.	Diff. for −1° Fa.
D. °	M. S.	S.	S.	S.
42	1 4·6	·038	2·16	·130
43	1 2·4	·036	2 09	·125
44	1 0 3	·034	2 02	·120
45	58·1	·034	1 94	·117
46	56 1	·033	1·88	·112
47	54·2	·032	1 81	·108
48	52·3	·031	1·75	·104
49	50 5	·030	1·69	·101
50	48 8	·029	1·63	·097
51	47·1	·028	1 58	·094
52	45 4	·027	1·52	·090
53	43 8	·026	1·47	·088
54	42·2	·026	1·41	·085
55	40·8	·025	1·36	·082
56	39 3	·025	1·31	·079
57	37·8	·025	1·26	·076
58	36·4	·024	1·22	·073
59	35·0	·024	1·17	·070
60	33·6	·023	1·12	·067
61	32 3	·022	1·08	·065
62	31·0	·022	1·04	·062
63	29·7	·021	·99	·060
64	28·4	·021	·95	·057
65	27·2	·020	·91	·055
66	25·9	·020	·87	·052
67	24 7	·020	·83	·050
68	23·5	·020	·79	·047
69	22·4	·020	·75	·045
70	21·2	·020	·71	·043
71	19 9	·020	·67	·040
72	18·8	·019	·63	·038
73	17·7	·018	·59	·036
74	16·6	·018	·56	·033
75	15·5	·018	·52	·031
76	14·4	·018	·48	·029
77	13·4	·017	·45	·027
78	12·3	·017	·41	·025
79	11·2	·017	·38	·023
80	10·2	·017	·34	·021
81	9·2	·017	·31	·018
82	8·2	·017	·27	·016
83	7·1	·017	·24	·014
84	6·1	·017	·20	·012
85	5·1	·017	·17	·010
86	4·1	·017	·14	·008
87	3·1	·017	·10	·006
88	2·0	·017	·07	·004
89	1·0	·017	·03	·002

TABLE F.

Parallax of the Sun.

Altitude.	January.	February and December.	March and November.	April and October.	May and September.	June and August.	July.
	"	"	"	"	"	"	"
0	8.95	8 93	8.87	8.80	8.72	8.67	8.65
4	8.93	8.91	8.85	8 78	8.70	8 65	8.63
8	8.85	8.84	8.79	8 71	8.64	8.58	8.57
12	8.75	8.73	8.68	8.61	8.54	8.48	8.47
16	8.60	8 58	8.53	8.46	8.39	8.34	8.32
20	8.41	8.39	8.34	8.27	8.20	8 15	8.13
24	8.18	8.16	8.10	8.04	7.97	7.92	7.91
28	7.90	7.88	7.84	7.77	7.70	7.65	7.64
32	7 59	7.57	7.53	7.46	7.40	7 36	7.34
36	7.24	7.22	7.18	7.12	7.06	7.02	7.00
40	6.86	6.84	6.80	6.74	6 69	6 64	6.63
44	6.44	6.42	6 39	6.33	6.28	6.24	6 23
48	5.99	5.98	5.94	5.89	5.84	5.80	5.79
52	5.51	5.51	5 46	5.42	5.37	5 34	5.33
56	5 01	4.99	4.96	4 92	4.88	4.85	4.84
58	4.74	4.73	4.70	4.66	4.63	4.60	4.59
60	4.47	4.46	4.43	4.40	4.36	4.33	4.32
62	4 20	4.19	4.17	4.13	4 10	4.07	4.06
64	3.92	3.91	3.89	3 86	3 82	3.80	3 79
66	3 64	3.63	3.61	3.58	3 55	3.53	3.52
68	3.35	3.34	3.32	3.30	3 27	3 25	3.24
70	3.06	3.05	3 03	3 01	2.98	2.97	2 96
72	2.77	2.76	2.74	2.72	2.70	2.68	2.68
74	2.47	2.46	2.45	2.43	2.41	2 39	2.38
76	2.17	2.16	2.15	2.13	2.11	2.10	2.10
80	1.55	1.55	1.54	1.53	1 52	1.51	1.50
84	0.94	0.93	0.93	0 92	0 91	0.91	0.90
86	0.62	0.62	0.62	0.61	0.61	0.61	0 60
88	0.31	0.31	0.31	0.31	0.31	0.30	0.30
90	0 00	0.00	0 00	0.00	0.00	0.00	0 00

TABLE G.

For Reversing Angles.

1'	2'	3'	4'	5'	6'	7'	8'	9	10'	11'	12'	13'	14'	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'	25'	26'	27'	28'	29'	30'
59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	[illegible]	30

0°	359°	20°	339°	40°	319°	60°	299°	80°	279°	100°	259°	120°	239°	140°	219°	160°	199°
1	358	21	338	41	318	61	298	81	278	101	258	121	238	141	218	161	198
2	357	22	337	42	317	62	297	82	277	102	257	122	237	142	217	162	197
3	356	23	336	43	316	63	296	83	276	103	256	123	236	143	216	163	196
4	355	24	335	44	315	64	295	84	275	104	255	124	235	144	215	164	195
5	354	25	334	45	314	65	294	85	274	105	254	125	234	145	214	165	194
6	353	26	333	46	313	66	293	86	273	106	253	126	233	146	213	166	193
7	352	27	332	47	312	67	292	87	272	107	252	127	232	147	212	167	192
8	351	28	331	48	311	68	291	88	271	108	251	128	231	148	211	168	191
9	350	29	330	49	310	69	290	89	270	109	250	129	230	149	210	169	190
10	349	30	329	50	309	70	289	90	269	110	249	130	229	150	209	170	189
11	348	31	328	51	308	71	288	91	268	111	248	131	228	151	208	171	188
12	347	32	327	52	307	72	287	92	267	112	247	132	227	152	207	172	187
13	346	33	326	53	306	73	286	93	266	113	246	133	226	153	206	173	186
14	345	34	325	54	305	74	285	94	265	114	245	134	225	154	205	174	185
15	344	35	324	55	304	75	284	95	264	115	244	135	224	155	204	175	184
16	343	36	323	56	303	76	283	96	263	116	243	136	223	156	203	176	183
17	342	37	322	57	302	77	282	97	262	117	242	137	222	157	202	177	182
18	341	38	321	58	301	78	281	98	261	118	241	138	221	158	201	178	181
19	340	39	320	59	300	79	280	99	260	119	240	139	220	159	200	179	180

TABLE H.

Comparative Scale of Fahrenheit's, Reaumer's, and the Centigrade Thermometers.

EQUIVALENTS TO FAHRENHEIT'S THERMOMETER.

Deg. Faht.	Deg. Reaum.	Deg. Centigr.	Deg. Faht.	Deg. Reaum.	Deg. Centigr.	Deg. Faht.	Deg. Reaum.	Deg. Centigr.	Deg. Faht.	Deg. Reaum.	Deg. Centigr.
			50	8·	10·	110	34·67	43·33	170	61·33	76·67
·1	·044	·056	51	8·44	10·56	111	35·11	43·89	171	61·78	77·22
·2	·089	·111	52	8·89	11·11	112	35·56	44·44	172	62·22	77·78
·3	·133	·167	53	9·33	11·67	113	36	45	173	62·68	78·33
·4	·178	·222	54	9·78	12·22	114	36·44	45·56	174	63·11	78·89
·5	·222	·278	55	10·22	12·78	115	36·89	46·11	175	63·56	79·44
·6	·267	·333	56	10·67	13·33	116	37·33	46·67	176	64	80
·7	·311	·389	57	11·11	13·89	117	37·78	47·22	177	64·44	80.56
·8	·356	·444	58	11·56	14·44	118	38·22	47·78	178	64·89	81.11
·9	·400	·500	59	12	15	119	38·67	48·33	179	65·33	81·67
0·	—14·22	—17·78	60	12·44	15·56	120	39·11	48·89	180	65·78	82·22
1	13·78	17·22	61	12·89	16·11	121	39·56	49·44	181	66·22	82·78
2	13·33	16·67	62	13·33	16·67	122	40	50	182	66·67	83·33
3	12·89	16·11	63	13·78	17·22	123	40·44	50·56	183	67·11	83·89
4	12·44	15·56	64	14·22	17·78	124	40·89	51·11	184	67·56	84·44
5	12	15	65	14·67	18·33	125	41·33	51·67	185	68	85·
6	11·56	14·44	66	15·11	18·89	126	41·78	52·22	186	68·44	85·56
7	11·11	13·89	67	15·56	19·44	127	42·22	52·78	187	68·89	86·11
8	10·67	13·33	68	16	20	128	42·67	53·33	188	69·33	86·67
9	10·22	12·78	69	16·44	20·56	129	43·11	53·89	189	69·78	87·22
10	9·78	12·22	70	16·89	21·11	130	43·56	54·44	190	70·22	87·78
11	9·33	11·67	71	17·33	21·67	131	44	55	191	70·67	88·33
12	8·89	11·11	72	17·78	22·22	132	44·44	55·56	192	71·11	88·89
13	8·44	10·56	73	18·22	22·78	133	44·89	56·11	193	71·56	89·44
14	8	10	74	18·67	23·33	134	45·33	56·67	194	72	90
15	7·56	9·44	75	19·11	23·89	135	45·78	57·22	195	72·44	90·56
16	7·11	8·89	76	19·56	24·44	136	46·22	57·78	196	72·89	91·11
17	6·67	8·33	77	20	25	137	46·67	58·33	197	73·33	91·67
[illegible]	6·22	7·78	78	20·44	25·56	138	47·11	58·89	198	73·78	92·22
19	5·78	7·22	79	20·89	26·11	139	47·56	59·44	199	74·22	92·78
20	5·33	6·67	80	21·33	26·67	140	48	60	200	74·67	93·33
21	4·89	6·11	81	21·78	27·22	141	48·44	60·56	201	75·11	93·89
22	4·44	5·56	82	22·22	27·78	142	48·89	61·11	202	75·56	94·44
23	4	5	83	22·67	28·33	143	49·33	61·67	203	76	95
[illegible]	3·56	4·44	84	23·11	28·89	144	49·78	62·22	204	76·44	95·56
[illegible]	3·11	3·89	85	23·56	29·44	145	50·22	62·78	205	76·89	96·11
[illegible]	2·67	3·33	86	24	30	146	50·67	63·33	206	77·33	96·67
[illegible]	2·22	2·78	87	24·44	30·56	147	51·11	63·89	207	7[illegible]·78	97·22
[illegible]	1·78	2·22	88	24·89	31·11	148	51·56	64·44	208	78·22	97·78
[illegible]	1·33	1·67	89	25·33	31·67	149	52	65	209	78·67	98·33
[illegible]	0·89	1·11	90	25·78	32·22	150	52·44	65·56	210	79·11	98·89
31	—0·44	—0·56	91	26·22	32·78	151	52·88	66·11	211	79·56	99·44
32	0	0	92	26·67	33·33	152	53·33	66·67	212	80	100
33	+0·44	+0·56	93	27·11	33·89	153	53·78	67·22	213	80·44	100·56
34	0·89	1·11	94	27·56	34·44	154	54·22	67·78	214	80·89	101·11
35	1·33	1·67	95	28	35	155	54·67	68·33	215	81·33	101·67
36	1·78	2·22	96	28·44	35·56	156	55·11	68·89	216	81·78	102·22
37	2·22	2·78	97	28·88	36·11	157	55·56	69·44	217	82.22	102·78
38	2·67	3·33	98	29·33	36·67	158	56	70	218	82·67	103·33
39	3·11	3·89	99	29·78	37·22	159	56·44	70·56	219	83·11	103·89
40	3·56	4·44	100	30·22	37·78	160	56·89	71·11	220	83·56	104·44
41	4	5	101	30·67	38·33	161	57·33	71·67	221	84	105
42	4·44	5·56	102	31·11	38·89	162	57·78	72·22	222	84·44	105·56
43	4·89	6·11	103	31·56	39·44	163	58·22	72·78	223	84·89	106·11
44	5·33	6·67	104	32	40	164	58·67	73·33	224	85·33	106·67
45	5·78	7·22	105	32·44	40·56	165	59·11	73·89	225	85·78	107·22
46	6·22	7·78	106	32·89	41·11	166	59·56	74·44	226	86·22	107·78
47	6·67	8·33	107	33·33	41·67	167	60	75	227	86·67	108·33
48	7·11	8·89	108	33·78	42·22	168	60·44	75·56	228	87·11	108·89
49	7·56	9·44	109	34·22	42·78	169	60·89	76·11	229	87·56	109·44
50	8	10	110	34·67	43·33	170	61·33	76·67	230	88	110

TABLE I.

For Converting Intervals of Sidereal Time into Equivalent Intervals of Mean Solar Time.

HOURS.		MINUTES.				SECONDS.			
Hours of Sidereal Time.	Equivalents in Mean Time.	Minutes of Sidereal Time.	Equivalents in Mean Time.	Minutes of Sidereal Time.	Equivalents in Mean Time.	Seconds of Sidereal Time.	Equivalents in Mean Time.	Seconds of Sidereal Time.	Equivalents in Mean Time.
	h. m. s.		m. s.		m. s.		s.		s.
1	0 59 50·1704	1	0 59·8362	31	30 54·9214	1	0·9973	31	30·9154
2	1 59 40·3409	2	1 59·6723	32	31 54·7576	2	1·9945	32	31·9126
3	2 59 30·5113	3	2 59·5085	33	32 54·5937	3	2·9918	33	32·9099
4	3 59 20·6818	4	3 59·3447	34	33 54·4299	4	3·9891	34	33·9072
5	4 59 10·8522	5	4 59·1809	35	34 54·2661	5	4·9864	35	34·9045
6	5 59 1·0226	6	5 59·0170	36	35 54·1023	6	5·9836	36	35·9017
7	6 58 51·1931	7	6 58·8532	37	36 53·9384	7	6·9809	37	36·8990
8	7 58 41·3635	8	7 58·6894	38	37 53·7746	8	7·9782	38	37·8963
9	8 58 31·5340	9	8 58·5256	39	38 53·6108	9	8·9754	39	38·8935
10	9 58 21·7044	10	9 58·3617	40	39 53·4470	10	9·9727	40	39·8908
11	10 58 11·8748	11	10 58·1979	41	40 53·2831	11	10·9700	41	40·8881
12	11 58 2·0453	12	11 58·0341	42	41 53·1193	12	11·9672	42	41·8853
13	12 57 52·2157	13	12 57·8703	43	42 52·9555	13	12·9645	43	42·8826
14	13 57 42·3862	14	13 57·7064	44	43 52·7917	14	13·9618	44	43·8799
15	14 57 32·5566	15	14 57·5426	45	44 52·6278	15	14·9591	45	44·8772
16	15 57 22·7270	16	15 57·3788	46	45 52·4640	16	15·9563	46	45·8744
17	16 57 12·8975	17	16 57·2150	47	46 52·3002	17	16·9536	47	46·8717
18	17 57 3·0679	18	17 57·0511	48	47 52·1364	18	17·9509	48	47·[illegible]90
19	18 56 53·2384	19	18 56·8873	49	48 51·9725	19	18·9481	49	48·8[illegible]62
20	19 56 43·4088	20	19 56·7235	50	49 51·8087	20	19·9454	50	49·86[illegible]5
21	20 56 33·5792	21	20 56·5597	51	50 51·6449	21	20·9427	51	50·86[illegible]8
22	21 56 23·7497	22	21 56·3958	52	51 51·4810	22	21·9399	52	51·8580
23	22 56 13·9201	23	22 56·2320	53	52 51·3172	23	22·9372	53	52·8553
24	23 56 4·0906	24	23 56·0682	54	53 51·1534	24	23·9345	54	53·8526
		25	24 55·9044	55	54 50·9896	25	24·9318	55	54·8499
		26	25 55·7405	56	55 50·8257	26	25·9290	56	55·8471
		27	26 55·5767	57	56 50·6619	27	26·9263	57	56·8444
		28	27 55·4129	58	57 50·4981	28	27·9236	58	57·8417
		29	28 55·2490	59	58 50·3343	29	28·9208	59	58·8389
		30	29 55·0852	60	59 50·1704	30	29·9181	60	59·8362

TABLE I.—(*Continued.*)

For Converting Intervals of Sidereal Time into Equivalent Intervals of Mean Solar Time.

Fractions of a Second.

Seconds of Sidereal Time.	Equivalents in Mean Time.	Seconds of Sidereal Time.	Equivalents in Mean Time.	Seconds of Sidereal Time.	Equivalents in Mean Time.
	s.		s.		s.
0·01	0·00997	0·34	0·33907	0·67	0·66817
0·02	0·01995	0·35	0·34904	0·68	0·67814
0·03	0·02992	0·36	0·35902	0·69	0·68812
0·04	0·03989	0·37	0·36899	0·70	0·69809
0·05	0·04986	0·38	0·37896	0·71	0·70806
0·06	0·05984	0·39	0·38894	0·72	0·71803
0·07	0·06981	0·40	0·39891	0·73	0·72801
0·08	0·07978	0·41	0·40888	0·74	0·73798
0·09	0·08975	0·42	0·41885	0·75	0·74795
0·10	0·09973	0·43	0·42883	0·76	0·75793
0·11	0·10970	0·44	0·43880	0·77	0·76790
0·12	0·11969	0·45	0·44877	0·78	0·77787
0·13	0·12965	0·46	0·45874	0·79	0·78784
0·14	0·13962	0·47	0·46872	0·80	0·79782
0·15	0·14959	0·48	0·47869	0·81	0·80779
0·16	0·15956	0·49	0·48866	0·82	0·81776
0·17	0·16954	0·50	0·49864	0·83	0·82773
0·18	0·17951	0·51	0·50861	0·84	0·83771
0·19	0·18948	0·52	0·51858	0·85	0·84768
0·20	0·19945	0·53	0·52855	0·86	0·85765
0·21	0·20943	0·54	0·53853	0·87	0·86762
0·22	0·21940	0·55	0·54850	0·88	0·87760
0·23	0·22937	0·56	0·55847	0·89	0·88757
0·24	0·23934	0·57	0·56844	0·90	0·89754
0·25	0·24932	0·58	0·57842	0·91	0·90752
0·26	0·25929	0·59	0·58839	0·92	0·91749
0·27	0·26926	0·60	0·59836	0·93	0·92746
0·28	0·27924	0·61	0·60833	0·94	0·93743
0·29	0·28921	0·62	0·61831	0·95	0·94741
0·30	0·29918	0·63	0·62828	0·96	0·95738
0·31	0·30915	0·64	0·63825	0·97	0·96735
0·32	0·31913	0·65	0·64823	0·98	0·97732
0·33	0·32910	0·66	0·65820	0·99	0·98730

Remarks.

This Table is useful for the conversion of Sidereal into Mean Solar Time.

Mean Solar Time *required* = Mean Time at the *preceding* Sidereal Noon + the Equivalent to the *given* Sidereal Time.

EXAMPLE.—To convert 21h 10m 50s·58 Sidereal Time at Greenwich, January 2, 1849, into Mean Time.

			d	h	m	s
Mean Time at the *preceding* Sidereal Noon, viz.		January	1	5	15	3·24
For Sidereal Intervals.	21h 0m 0s	The Table gives the Equivalent Mean Intervals.		20	56	33·58
	10 0				9	58 36
	50					49 86
	0·58					·58
The Sum is the Mean Time required,		January	2	2	22	25·62

TABLE J.

For Converting Intervals of Mean Solar Time into Equivalent Intervals of Sidereal Time.

Hours.		Minutes.				Seconds.			
Hours of Mean Time.	Equivalents in Sidereal Time.	Minutes of Mean Time.	Equivalents in Sidereal Time.	Minutes of Mean Time.	Equivalents in Sidereal Time.	Seconds of Mean Time.	Equivalents in Sidereal Time	Seconds of Mean Time.	Equivalents in Sidereal Time.
	h. m. s.		m. s.		m. s.		s.		s.
1	1 0 9·8565	1	1 0·1643	31	31 5·0925	1	1·0027	31	31·0849
2	2 0 19·7130	2	2 0·3286	32	32 5·2568	2	2·0055	32	32·0876
3	3 0 29·5694	3	3 0·4928	33	33 5·4211	3	3·0082	33	33·0904
4	4 0 39·4259	4	4 0·6571	34	34 5·5853	4	4·0110	34	34·0931
5	5 0 49·2824	5	5 0·8214	35	35 5·7496	5	5·0137	35	35·0958
6	6 0 59·1388	6	6 0·9857	36	36 5·9139	6	6·0164	36	36·0986
7	7 1 8·9953	7	7 1·1499	37	37 6·0782	7	7·0192	37	37·1013
8	8 1 18·8518	8	8 1·3142	38	38 6·2424	8	8·0219	38	38·1040
9	9 1 28·7083	9	9 1·4785	39	39 6·4067	9	9·0246	39	39·1068
10	10 1 38·5647	10	10 1·6428	40	40 6·5710	10	10·0274	40	40·1095
11	11 1 48·4212	11	11 1·8070	41	41 6·7353	11	11·0301	41	41·1123
12	12 1 58·2777	12	12 1·9713	42	42 6·8995	12	12·0329	42	42·1150
13	13 2 8·1342	13	13 2·1356	43	43 7·0638	13	13·0356	43	43·1177
14	14 2 17·9906	14	14 2·2998	44	44 7·2281	14	14·0383	44	44·1205
15	15 2 27·8471	15	15 2·4641	45	45 7·3924	15	15·0411	45	45·1232
16	16 2 37·7036	16	16 2·6284	46	46 7·5566	16	16·0438	46	46·1259
17	17 2 47·5600	17	17 2·7927	47	47 7·7209	17	17·0465	47	47·1287
18	18 2 57·4165	18	18 2·9569	48	48 7·8852	18	18·0493	48	48·1314
19	19 3 7·2730	19	19 3·1212	49	49 8·0495	19	19·0520	49	49·13[illegible]
20	20 3 17·1295	20	20 3·2855	50	50 8·2137	20	20·0548	50	50·1369
21	21 3 26·9859	21	21 3·4498	51	51 8·3780	21	21·0575	51	51·13[illegible]
22	22 3 36·8424	22	22 3·6140	52	52 8·5423	22	22·0602	52	52·1424
23	23 3 46·6989	23	23 3·7783	53	53 8·7066	23	23·0630	53	53·1451
24	24 3 56·5554	24	24 3·9426	54	54 8·8708	24	24·0657	54	54·1479
		25	25 4·1069	55	55 9·0351	25	25·0685	55	55·1506
		26	26 4·2711	56	56 9·1994	26	26·0712	56	56·1533
		27	27 4·4354	57	57 9·3637	27	27·0739	57	57·1561
		28	28 4·5997	58	58 9·5279	28	28·0767	58	58·1588
		29	29 4·7640	59	59 9·6922	29	29·0794	59	59·1615
		30	30 4·9282	60	60 9·8565	30	30·0821	60	60·1643

TABLE J.—(*Continued.*)

For Converting Intervals of Mean Solar Time into Equivalent Intervals of Sidereal Time.

FRACTIONS OF A SECOND.

Seconds of Mean Time.	Equivalents in Sidereal Time.	Seconds of Mean Time.	Equivalents in Sidereal Time.	Seconds of Mean Time.	Equivalents in Sidereal Time.
	s.		s.		s.
0·01	0·01003	0·34	0·34093	0·67	0·67183
0·02	0·02006	0·35	0·35096	0·68	0·68186
0·03	0·03008	0·36	0·36099	0·69	0·69189
0·04	0·04011	0·37	0·37101	0·70	0·70192
0·05	0·05014	0·38	0·38104	0·71	0·71194
0·06	0·06016	0·39	0·39107	0·72	0·72197
0·07	0·07019	0·40	0·40110	0·73	0·73200
0·08	0·08022	0·41	0·41112	0·74	0·74203
0·09	0·09025	0·42	0·42115	0·75	0·75205
0·10	0·10027	0·43	0·43118	0·76	0·76208
0·11	0·11030	0·44	0·44120	0·77	0·77211
0·12	0·12033	0·45	0·45123	0·78	0·78214
0·13	0·13036	0·46	0·46126	0·79	0·79219
0·14	0·14038	0·47	0·47129	0·80	0·80219
0·15	0·15041	0·48	0·48131	0·81	0·81222
0·16	0·16044	0·49	0·49134	0·82	0·82225
0·17	0·17047	0·50	0·50137	0·83	0.83227
0·18	0·18049	0·51	0·51140	0·84	0·84230
0·19	0·19052	0·52	0·52142	0·85	0·85233
0·20	0·20055	0·53	0·53145	0·86	0·86235
0·21	0·21057	0·54	0·54148	0·87	0·87238
0·22	0·22060	0·55	0·55151	0·88	0·88241
0·23	0·25063	0·56	0·56153	0·89	0·89244
0·24	0·24066	0·57	0·57156	0·90	0·90246
0·25	0·25068	0·58	0·58159	0·91	0·91249
0·26	0·26071	0·59	0·59162	0·92	0·92252
0·27	0·27074	0·60	0·60164	0·93	0·93255
0·28	0·28077	0·61	0·61167	0·94	0·94257
0·29	0·29079	0·62	0·62170	0·95	0·95260
0·30	0·30082	0·63	0·63173	0·96	0·96263
0·31	0·31085	0·64	0·64175	0·97	0·97266
0·32	0·32088	0·65	0·65178	0·98	0·98268
0·33	0·33099	0·66	0·66181	0·99	0·99271

REMARKS.

This Table is useful for the conversion of Mean Solar into Sidereal Time.

Sidereal Time = Sidereal Time at the *preceding* Mean Noon + the Equivalent to the *given* Mean Time.

EXAMPLE.—To convert 2h 22m 50s 62 Mean Time at Greenwich, January 2, 1849, into Sidereal Time.

		h	m	s
Sidereal Time at the *preceding* Mean Noon, *viz.*, January 2	..	18	48	1·56
For Mean Intervals: 2h 0m 0s; 22 0; 25; 0 62	This Table gives the Equivalent Sidereal Intervals.	2	0	19·71
			22	3·62
				25·07
				0·62
The Sum is the Sidereal Time required	..	21	10	50·58

TABLE K.

Shewing the correction to be applied to a Barometer with a Brass Scale, extending from the Cistern to the Top of the Mercurial Column, to reduce the Observation to 32° Fahrenheit.

Temperature Fahrenheit.	OBSERVED HEIGHTS OF THE BAROMETER IN INCHES.											
	28·1	28·2	28·3	28·4	28·5	28·6	28·7	28·8	28 9	29·0	29·1	29·2
50°	·054	·054	·054	·055	·055	·055	·055	·055	056	·056	·056	·056
51	·057	057	·057	·057	·057	·058	·058	·058	·058	·058	·059	·059
52	·059	·059	·059	060	·060	·060	·060	·061	·061	·061	·061	·061
53	·062	·062	·062	·062	·062	·063	·063	·063	·063	·064	·064	·064
54	·064	·064	·065	·065	·065	·065	·065	·066	·066	·066	·066	·067
55	·067	·067	·067	·067	·068	·068	·068	·068	068	·069	·069	·069
56	·069	·069	·070	·070	·070	070	·071	·071	·071	·071	·072	·072
57	·072	·072	·072	·072	·073	·073	·073	·073	·074	·074	074	·074
58	·074	·074	·075	·075	·075	·075	076	·076	·076	·076	·077	·077
59	·077	·077	·077	·077	·078	·078	·078	·078	·079	·079	·079	.080
60	·079	·079	·080	·080	·080	·080	·081	·081	·081	·082	·082	.082
61	·082	·082	·082	·082	·083	·083	·083	·084	·084	·084	·084	.085
62	·084	·084	·085	·085	·085	·086	·086	·086	086	·087	·087	.087
63	·087	·087	·087	·087	·088	·088	·088	·089	·089	·089	·090	.090
64	·089	·089	·090	·090	·090	091	·091	·091	·092	·092	·092	.093
65	·092	·092	·092	·093	·093	·093	·093	·094	·094	·094	·095	.095
66	·094	·094	·095	·095	·095	·096	·096	·096	097	·097	·097	.098
67	·097	·097	·097	·098	·098	·098	·099	·099	·099	·100	·100	.100
68	·099	·099	·100	·100	·100	·101	·101	·101	·102	·102	·103	.103
69	·102	·102	·102	·103	·103	·103	·104	·104	·104	·105	·105	.105
70	·104	·104	·105	·105	·105	·106	·106	·107	·107	·107	·108	.108
71	·106	·107	·107	·108	·108	·108	·109	·109	·110	·110	·110	.111
72	·109	·109	·110	·110	·111	·111	·111	112	·112	·112	·113	.113
73	·111	·112	·112	·113	·113	·113	·114	·114	115	·115	·115	.116
74	·114	·114	·115	·115	·116	·116	·116	·117	·117	·118	·118	.118
75	·116	·117	·117	·118	·118	·119	·119	·119	·120	·120	·121	.121
76	·119	·119	·120	·120	·121	·121	·121	·122	·122	·123	·123	.124
77	·121	·122	·122	·123	·123	·124	·124	·124	·125	·125	·126	.126
78	·124	·124	·125	·125	·126	·126	·127	·127	·127	·128	·128	.129
79	·126	·127	·127	·128	·128	·129	·129	·130	·130	·130	·131	.131
80	·129	·129	·130	·130	·131	·131	·132	·132	·133	·133	·133	.134
81	·131	·132	·132	·133	·133	·134	·134	·135	·135	·136	·136	.137
82	·134	·134	·135	·135	·136	·136	·137	·137	·138	·138	·139	.139
83	·136	·137	·137	·138	·138	139	·139	·140	·140	·141	·141	.142
84	·139	·139	·140	·140	·141	·141	·142	·142	·143	·143	·144	.144
85	·141	·142	·142	·143	·143	·144	·144	·145	·145	·146	·146	·147
86	·144	·144	·145	·145	·146	·146	·147	·147	·148	·148	·149	·149
87	·146	·147	·147	·148	·148	·149	149	·150	·150	·151	·152	·152
88	·149	·149	·150	·150	·151	·151	·152	·152	·153	·154	·154	[illegible]
89	·151	·152	·152	·153	·153	·154	·154	·155	·156	·156	·157	[illegible]
90	·154	·154	·155	·155	·156	·156	·157	·158	·158	·159	·159	·160
91	·156	·157	·157	·158	·158	·159	·160	·160	·161	·161	·162	·162
92	·159	·159	·160	·160	·161	·162	·162	·163	·163	·164	·164	·165
93	·161	·162	·162	·163	·163	·164	·165	·165	·166	·166	·167	·168
94	·164	·164	·165	·165	·166	·167	·167	·168	·168	·169	·169	·170
95	·166	·167	·167	·168	·169	·169	·170	·170	·171	·171	·172	·173
96	·169	·169	·170	·170	·171	·172	·172	·173	·173	·174	·175	·175
97	·171	·172	·172	·173	·174	·174	·175	·175	·176	·177	·177	·178
98	·174	·174	·175	·175	·176	·177	·177	·178	·179	·179	·180	·180
99	·176	·177	·177	·178	·179	·179	·180	·180	·181	·182	·182	·183
100	·179	·179	·180	·180	·181	·182	·182	·183	·184	·184	·185	·186
101	·181	·182	·182	·183	·184	·184	·185	·186	·186	·187	·187	·188
102	·184	·184	·185	·185	·186	·187	·187	·188	·189	·189	·190	·191
103	·186	·187	·187	·188	·189	·189	·190	·191	·191	·192	·193	·193
104	·188	·189	·190	·190	·191	·192	·192	·193	·194	·194	·195	·196
105	·191	·192	·192	·193	·194	·194	·195	·196	·196	·197	·198	·198
106	·193	·194	·195	·195	·196	·197	·198	·198	·199	·200	·200	·201
107	·196	·197	·197	·198	·199	·199	·200	·201	·201	·202	·203	·204
108	·198	·199	·200	·200	·201	·202	·203	·203	·204	·205	·205	·206
109	·201	·202	·202	·203	·204	·204	·205	·206	·207	·207	·208	·209
110	·203	·204	·205	·205	·206	·207	·208	·208	·209	·210	211	·211

TABLE K.—(*Continued.*)

Shewing the correction to be applied to a Barometer with a Brass Scale, extending from the Cistern to the Top of the Mercurial Column, to reduce the Observation to 32° Fahrenheit.

Temperature Fahrenheit.	Observed Heights of the Barometer in Inches.											
	29·3	29·4	29·5	29·6	29·7	29·8	29·9	30·0	30·1	30·2	30·3	30·4
50	·056	·057	·057	·057	·057	·057	·058	·058	·058	·058	·058	·058
51	·059	·059	·059	·060	·060	·060	·060	·060	·061	·061	·061	·061
52	·062	·062	·062	·062	·062	·063	·063	·063	·063	·063	·064	·064
53	·064	·064	·065	·065	·065	·065	·066	·066	·066	·066	·066	·067
54	·067	·067	·067	·067	·068	·068	·068	·068	·069	·069	·069	·069
55	·069	·070	·070	·070	·070	·071	·071	·071	·071	·072	·072	·072
56	072	·072	·073	·073	·073	·073	·073	·074	·074	·074	·075	·075
57	·075	·075	·075	·075	·076	·076	·076	·076	·077	·077	·077	·077
58	·077	·077	·078	·078	·078	·079	·079	·079	·079	·080	·080	·080
59	·080	·080	·080	·081	·081	·081	·081	082	·082	·082	·083	·083
60	·082	·083	·083	·083	·084	·084	·084	·084	·085	·085	·085	·086
61	·085	085	·086	·086	·086	·086	·087	·087	·087	·088	·088	·088
62	·088	·088	·088	·089	·089	·089	·089	·090	·090	·090	·091	·091
63	·090	·091	·091	·091	·091	·092	·092	·092	·093	·093	·093	·094
64	·093	·093	·093	·094	·094	·094	·095	·095	·095	·096	·096	·096
65	·095	·096	·096	·096	·097	·097	·097	·098	·098	·098	·099	·099
66	·098	·098	·099	·099	·099	·100	·100	·100	·101	·101	·101	·102
67	·101	·101	·101	·102	·102	·102	·103	·103	·103	·104	·104	·104
68	·103	·104	·104	·104	·105	·105	·105	·106	·106	·106	·107	·107
69	·106	·106	·107	·107	·107	·108	·108	·108	·109	·109	·109	·110
70	·108	·109	·109	·110	·110	·110	·111	·111	·111	·112	·112	·113
71	·111	·111	·112	·112	·113	·113	·113	·114	·114	·114	·115	·115
72	·114	·114	·114	·115	·115	·116	·116	·116	·117	·117	·118	·118
73	·116	·117	·117	·117	·118	·118	·119	·119	·119	·120	·120	·121
74	·119	·119	·120	·120	·120	·121	·121	·122	·122	·122	·123	·123
75	·121	·122	·122	·123	·123	·124	·124	·124	·125	·125	·126	·126
76	·124	·124	·125	·125	·126	·126	·127	·127	·127	·128	·128	·129
77	·127	·127	·127	·128	·128	·129	·129	·130	·130	·131	·131	·131
78	·129	·130	·130	·131	·131	·131	·132	·132	·133	·133	·134	·134
79	·132	·132	·133	·133	·134	·134	·135	·135	·135	·136	·136	·137
80	·134	·135	·135	·136	·136	·137	·137	·138	·138	·139	·139	·139
81	·137	·137	·138	·138	·139	·139	·140	·140	·141	·141	·142	·142
82	·140	·140	·141	·141	·141	·142	·142	·143	·143	·144	·144	·145
83	·142	·143	·143	·144	·144	·145	·145	·146	·146	·147	·147	·148
84	·145	·145	·146	·146	·147	·147	·148	·148	·149	·149	·150	·150
85	·147	·148	·148	·149	·149	·150	·150	·151	·151	·152	·152	·153
86	·150	·150	·151	·151	·152	·153	·153	·154	·154	·155	·155	·156
87	·153	·153	·154	·154	·155	·155	·156	·156	·157	·157	·158	·158
88	·155	·156	·156	·157	·157	·158	·158	·159	·159	·160	·160	·161
89	·158	·158	·159	·159	·160	·160	·161	·161	·162	·163	·163	·164
90	·160	·161	·161	·162	·163	·163	·164	·164	·165	·165	·166	·166
91	·163	·163	·164	·165	·165	·166	·166	·167	·167	·168	·168	·169
92	·165	·166	·167	·167	·168	·168	·169	·169	·170	·171	·171	·172
93	·168	·169	·169	·170	·170	·171	·172	·172	·173	·173	·174	·174
94	·171	·171	·172	·172	·173	·174	·174	·175	·175	·176	·176	·177
95	·173	·174	·174	·175	·176	·176	·177	·177	·178	·179	·179	·180
96	·176	·176	·177	·178	·178	·179	·179	·180	·181	·181	·182	·182
97	·178	·179	·180	·180	·181	·181	·182	·183	·183	·184	·185	·185
98	·181	·182	·182	·183	·183	·184	·185	·185	·186	·187	·187	·188
99	·184	·184	·185	·185	·186	·187	·187	·188	·189	·189	·190	·190
100	·186	·187	·187	·188	·189	·189	·190	·191	·191	·192	·193	·193
101	·189	·189	·190	·191	·191	·192	·193	·193	·194	·195	·195	·196
102	·191	·192	·193	·193	·194	·195	·195	·196	·197	·197	·198	·199
103	·194	·195	·195	·196	·197	·197	·198	·199	·199	·200	·201	·201
104	·197	·197	·198	·199	·199	·200	·201	·201	·202	·203	·203	·204
105	·199	·200	·200	·201	·202	·202	·203	·204	·205	·205	·206	·207
106	·202	·202	·203	·204	·204	·205	·206	·206	·207	·208	·209	·209
107	·204	·205	·206	·206	·207	·208	·208	·209	·210	·211	·211	·212
108	·207	·208	·208	·209	·210	·210	·214	·212	·212	·213	·214	·215
109	·209	·210	·211	·212	·212	·213	·218	·214	·215	·216	·217	·217
110	·212	·213	·213	·214	·215	·216	·216	·217	·218	·218	·219	·220

TABLE L.

For Converting Acres into Corresponding Beegahs of 80 Haths, or 1,600 Square Yards.

Acres.	Beegahs 0.	Beegahs 1.	Beegahs 2.	Beegahs 3.	Beegahs 4.	Beegahs 5.	Beegahs 6.	Beegahs 7.	Beegahs 8.	Beegahs 9.
		3·025	6·050	9·075	12·100	15·125	18·150	21·175	24·200	27 225
10	30·250	33·275	36·300	39·325	42·350	45·375	48·400	51·425	54·450	57·475
20	60·500	63·525	66·550	69·575	72·600	75·625	78·650	81·675	84·700	87·725
30	90·750	93·775	96·800	99·825	102·850	105·875	108·900	111·925	114·950	117·975
40	121·000	124·025	127·050	130·075	133·100	136·125	139·150	142·175	145·200	148·225
50	151·250	154·275	157·300	160·325	163·350	166·375	169·400	172·425	175·450	178·475
60	181·500	184·525	187·550	190·575	193·600	196·625	199·650	202·675	205·700	208·725
70	211·750	214·775	217·800	220·825	223·850	226·875	229·900	232·925	235·950	238·975
80	242·000	245·025	248·050	251·075	254·100	257·125	260·150	263·175	266·200	269·225
90	272·250	275·275	278·300	281·325	284·350	287 375	290·400	293·425	296·450	299·475

Note.—This Table gives the number of Beegahs corresponding with Acres from 1 to 99, any number above must be taken out by removing the decimal point one, two, or as many places to the right as there are figures in excess of those given in the Table, and any decimal of an Acre by removing the point in the same manner to the left.—Thus: the number of Beegahs corresponding with 836 74 Acres is 830 Acres .. .. 2510 75 Beegahs.

830 Acres	.. ..	2510 75 Beegahs.
6 „	.. ..	18·15
0 74 „	.. ..	2·23
		2531·13 Beegahs.

TABLE M.

For Converting Beegahs of 80 Huths or 1600 Square Yards into Corresponding Acres.

Beegahs.	Acres. 0.	Acres. 1.	Acres. 2.	Acres. 3.	Acres. 4.	Acres. 5.	Acres. 6.	Acres. 7.	Acres. 8.	Acres. 9.
		·33058	·66116	·99174	1·32232	1·65290	1·98348	2·31406	2·64464	2·97522
10	3·3058	3·63638	3·96696	4·29754	4·62812	4·95870	5·28928	5·61986	5·95044	6·28102
20	6·6116	6·94218	7·27276	7·60334	7·93392	8·26450	8·59508	8·92566	9·25624	9·58682
30	9·9174	10·24798	10·57856	10·90914	11·23972	11·57030	11·90088	12·23146	12·56204	12·89262
40	13·2232	13·55378	13·88436	14·21494	14·54552	14·87610	15·20668	15·53726	15·86784	16·19842
50	16·5290	16·85958	17·19016	17·52074	17·85132	18·18190	18·51248	18·84306	19·17364	19·50422
60	19·8348	20·16538	20·495[illegible]6	20·82654	21·15712	21·48770	21·81828	22·14886	22·47944	22·81002
70	23·1406	23·47118	23·80176	24·13234	24·46292	24·79350	25·12408	25·45466	25·78524	26·11582
80	26·4464	26·77698	27·10756	27·43814	27·76872	28·09930	28·42988	28·76046	29·09104	29·42162
90	29·7522	30·08278	30·41336	30·74394	31·07452	31·40510	31·73568	32·06626	32·39684	32·72742

NOTE.—This Table gives the number of Acres corresponding with Beegahs from 1 to 99, and is made use of in the same manner as Table L. Thus: the number of Acres corresponding with 2531·13 Beegahs, is 2500 Beegahs .. 826·45 Acres.

31 „ .. 10·247

0 13 „ .. 0·043

836 74 Acres.

TABLE N.

For Converting the Decimal Part of an Acre or Bengal Beegah into its corresponding value of Roods and Poles, or Cottahs and Chittacks.

Dec. of Acre or Beegah.	Acre. ·0 R—P	Beegah. ·0 C—C	Acre. ·01 R—P	Beegah. 01 C—C	Acre. 02 R—P	Beegah. 02 C—C	Acre. 03 R—P	Beegah ·03 C—C	Acre. ·04 R—P	Beegah ·04 C—C	Acre. 05 R—P	Beegah. ·05 C—C	Acre. ·06 R—P	Beegah. ·06 C—C	Acre. ·07 R—P	Beegah. ·07 C—C	Acre. ·08 R—P	Beegah. ·08 C—C	Acre. ·09 R—P	Beegah. ·09 C—C
			0 2	0 3	0 4	0 6	0 6	0 10	0 7	0 13	0 9	1 0	0 11	1 3	0 12	1 6	0 14	1 10	0 15	1 13
·10	0 17	2 0	0 19	2 3	0 20	2 6	0 22	2 10	0 23	2 13	0 25	3 0	0 27	3 3	0 28	3 6	0 30	3 10	0 31	3 13
·20	0 33	4 0	0 35	4 3	0 36	4 6	0 38	4 19	0 39	4 13	1 0	5 0	1 2	5 3	1 4	5 6	1 6	5 10	1 7	5 13
·30	1 9	6 0	1 11	6 3	1 12	6 6	1 14	6 10	1 15	6 13	1 17	7 0	1 19	7 3	1 20	7 6	1 22	7 10	1 23	7 13
·40	1 25	8 0	1 27	8 3	1 28	8 6	1 30	8 10	1 31	8 13	1 33	9 0	1 35	9 3	1 36	9 6	1 38	9 10	1 39	9 13
·50	2 0	10 0	2 2	10 3	2 4	10 6	2 6	10 10	2 17	10 13	2 9	11 0	2 11	11 3	2 12	11 6	2 14	11 10	2 15	11 13
·60	2 17	12 0	2 19	12 3	2 20	12 6	2 22	12 10	2 23	12 13	2 25	13 0	2 27	13 3	2 28	13 6	2 30	13 10	2 31	13 13
·70	2 33	14 0	2 35	14 3	2 36	14 6	2 38	14 10	2 39	14 13	3 0	15 0	3 2	15 3	3 4	15 6	3 6	15 10	3 7	15 13
·80	3 9	16 0	3 11	16 3	3 12	16 6	3 14	16 10	3 15	16 13	3 17	17 0	3 19	17 3	3 20	17 6	3 22	17 10	3 23	17 13
·90	3 25	18 0	3 27	18 3	3 28	18 6	3 30	18 10	3 31	18 13	3 33	19 0	3 35	19 3	3 36	19 6	3 38	19 10	3 39	19 13

This Table gives the number of Roods and Poles, or Cottahs and Chittacks, corresponding with any decimal part of an Acre or Beegah, and is used in a similar manner as Tables L and M.

EXAMPLE.

Required the number of Beegahs corresponding with 8348 Acres, 2 Roods and 12 Poles, and also the number of Acres corresponding with 25254 Beegahs, 8 Cottahs and 6 Chittacks?

BY TABLE L.

	8300	Acres	25107 50 Beegahs.
	48	"	145 20
R P, 2 12 by Table N	0 57	"	1 72
			25254·42 or

B.	C.	C.
25254	8	6

BY TABLE M.

	25000	Beegahs	8264·50 Acres.
	250	"	82 64
	4	"	1 32
C. C 8 6 by Table N	0·42	"	·13
			8348 59 or

A	R.	P.
8348	2	15

It will be evident in the above examples, that the difference of 3 Poles between the two calculations, is in consequence of the decimals not being carried beyond two places in Table N. In practice such a trifling difference is of little moment in an area of upwards of 25000 Beegahs.

TABLE O.

Of Square Measure for Bengal Standard Beegah of 14400 *Square Feet, or* 1600 *Square Yards.*

TABLE OF SQUARE MEASURE.

Sq Ft.		Gundah.		Chittack.		Cottah.		Beegah.		Acre.
45	=	20	=	1						
720	=	320	=	16	=	1				
14400	=	6600	=	320	=	20	=	1		
43560	=	19360	=	968	=	60·5	=	3·025	=	1

Rule for Duodecimals.—Under the terms of the Multiplicand write the corresponding denominations of the Multiplier, so that Beegahs may stand under Beegahs, Cottahs under Cottahs, and Chittacks under Chittacks. Then multiply each term in the Multiplicand, beginning at the lowest, by the Beegahs in the Multiplier, and write the result under its respective term. In the same manner multiply all the terms of the Multiplicand by the Cottahs in the Multipliers, and write the result one place removed to the right hand of those in the Multiplicand. Proceed in like manner with the Chittacks, and the sum of all these products will give the area required.

Beegahs by Beegahs. (1.)

Beegahs.	1	2	3	4	5	6	7	8	9	10
1	1	2	3	4	5	6	7	8	9	10
2	2	4	6	8	10	12	14	16	18	20
3	3	6	9	12	15	18	21	24	27	30
4	4	8	12	16	20	24	28	32	36	40
5	5	10	15	20	25	30	35	40	45	50
6	6	12	18	24	30	36	42	48	54	60
7	7	14	21	28	35	42	49	56	63	70
8	8	16	24	32	40	48	56	64	72	80
9	9	18	27	36	45	54	63	72	81	90
10	10	20	30	40	50	60	70	80	90	100

Rule for Tables.—Take out from each Table the quantity required, placing it under its respective term (agreeably to the rule given for Duodecimals) for Beegahs, Cottahs and Chittacks, the sum will be the area required.

EXAMPLE.

Required the area of a Field, the breadth being 4 B., 8 C., 9 C., and the length 5 B., 10 C., 6 C. ?

		B.	C.	C.		
		4	8	9		
		5	10	6		
Table	1 -	20				5×4
,,	2 -	2				5×8
,,	3 -	0	2	13		5×9
,,	2 -	2				10×4
,,	4 -	0	4			10×8
,,	5 -	0	0	10		10×9
,,	3 -	0	1	8		6×4
,,	5 -	0	0	2	8	6×8
,,	6 -	0	0	0	3·37	6×9
		24	8	12	1·37	Area required, or 24 Beegahs, 8 Cottahs, 12 Chittacks, and 1·37 Gundahs.

NOTE.—In practice it would be unnecessary to carry out the calculation to the extent of Gundahs, unless very great accuracy were required.

Beegahs by Cottahs. (2.)

Cot.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
B.	B. C. C.	B. C. C.	B. C. C.	B. C. C.	B. C. C.	B. C. C.	B. C. C.	B. C. C.	B. C. C.	B C. C.	B. C. C.	B. C. C.	B. C. C.	B. C. C.	B. C. C.	B. C. C	B. C. C	B. C. C.	B. C. C.
1	0 1 0	0 2 0	0 3 0	0 4 0	0 5 0	0 6 0	0 7 0	0 8 0	0 9 0	0 10 0	0 11 0	0 12 0	0 13 0	0 14 0	0 15 0	0 16 0	0 17 0	0 18 0	0 19 0
2	0 2 0	0 4 0	0 6 0	0 8 0	0 10 0	0 12 0	0 14 0	0 16 0	0 18 0	1 0 0	1 2 0	1 4 0	1 6 0	1 8 0	1 10 0	1 12 0	1 14 0	1 16 0	1 18 0
3	0 3 0	0 6 0	0 9 0	0 12 0	0 15 0	0 18 0	1 1 0	1 4 0	1 7 0	1 10 0	1 13 0	1 16 0	1 19 0	2 2 0	2 5 0	2 8 0	2 11 0	2 14 0	2 17 0
4	0 4 0	0 8 0	0 12 0	0 16 0	1 0 0	1 4 0	1 8 0	1 12 0	1 16 0	2 0 0	2 4 0	2 8 0	2 12 0	2 16 0	3 0 0	3 4 0	3 8 0	3 12 0	3 16 0
5	0 5 0	0 10 0	0 15 0	1 0 0	1 5 0	1 10 0	1 15 0	2 0 0	2 5 0	2 10 0	2 15 0	3 0 0	3 5 0	3 10 0	3 15 0	4 0 0	4 5 0	4 10 0	4 15 0
6	0 6 0	0 12 0	0 18 0	1 4 0	1 10 0	1 16 0	2 2 0	2 8 0	2 14 0	3 0 0	3 6 0	3 12 0	3 18 0	4 4 0	4 10 0	4 16 0	5 2 0	5 8 0	5 14 0
7	0 7 0	0 14 0	1 1 0	1 8 0	1 15 0	2 2 0	2 9 0	2 16 0	3 3 0	3 10 0	3 17 0	4 4 0	4 11 0	4 18 0	5 5 0	5 12 0	5 19 0	6 6 0	6 13 0
8	0 8 0	0 16 0	1 4 0	1 12 0	2 0 0	2 8 0	2 16 0	3 4 0	3 12 0	4 0 0	4 8 0	4 16 0	5 4 0	5 12 0	6 0 0	6 8 0	6 16 0	7 4 0	7 12 0
9	0 9 0	0 18 0	1 7 0	1 16 0	2 5 0	2 14 0	3 3 0	3 12 0	4 1 0	4 10 0	4 19 0	5 8 0	5 17 0	6 6 0	6 15 0	7 4 0	7 13 0	8 2 0	8 11 0
10	0 10 0	1 0 0	1 10 0	2 0 0	2 10 0	3 0 0	3 10 0	4 0 0	4 10 0	5 0 0	5 10 0	6 0 0	6 10 0	7 0 0	7 10 0	8 0 0	8 10 0	9 0 0	9 10 0

TABLE O.—(*Continued.*)

Beegahs by Chittacks. (3.)

Chittacks.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Beegahs.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.
1	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	0 10	0 11	0 12	0 13	0 14	0 15
2	0 2	0 4	0 6	0 8	0 10	0 12	0 14	1 0	1 2	1 4	1 6	1 8	1 10	1 12	1 14
3	0 3	0 6	0 9	0 12	0 15	1 2	1 5	1 8	1 11	1 14	2 1	2 4	2 7	2 10	2 13
4	0 4	0 8	0 12	1 0	1 4	1 8	1 12	2 0	2 4	2 8	2 12	3 0	3 4	3 8	3 12
5	0 5	0 10	0 15	1 4	1 9	1 14	2 3	2 8	2 13	3 2	3 7	3 12	4 1	4 6	4 11
6	0 6	0 12	1 2	1 8	1 14	2 4	2 10	3 0	3 6	3 12	4 2	4 8	4 14	5 4	5 10
7	0 7	0 14	1 5	1 12	2 3	2 10	3 1	3 8	3 15	4 6	4 13	5 4	5 11	6 2	6 9
8	0 8	1 0	1 8	2 0	2 8	3 0	3 8	4 0	4 8	5 0	5 8	6 0	6 8	7 0	7 8
9	0 9	1 2	1 11	2 4	2 13	3 6	3 15	4 8	5 1	5 10	6 3	6 12	7 5	7 14	8 7
10	0 10	1 4	1 14	2 8	3 2	3 12	4 6	5 0	5 10	6 4	6 14	7 8	8 2	8 12	9 6

Cottahs by Cottahs. (4.)

Cot.	1	2	3	4	5	6	7	8	9	10
Cot.	C. C. G.	C. C. G.	C. C. G.	C. C. G.	C. C. G.	C. C. G.	C. C. G.	C. C. G.	C. C. G.	C. C. G.
1	0 0 16	0 1 12	0 2 8	0 3 4	0 4 0	0 4 16	0 5 12	0 6 8	0 7 4	0 8 0
2	0 1 12	0 3 4	0 4 16	0 6 8	0 8 0	0 9 12	0 11 4	0 12 16	0 14 8	1 0 0
3	0 2 8	0 4 16	0 7 4	0 9 12	0 12 0	0 14 8	1 0 16	1 3 4	1 5 12	1 8 0
4	0 3 4	0 6 8	0 9 12	0 12 16	1 0 0	1 3 4	1 6 8	1 9 12	1 12 16	2 0 0
5	0 4 0	0 8 0	0 12 0	1 0 0	1 4 0	1 8 0	1 12 0	2 0 0	2 4 0	2 8 0
6	0 4 16	0 9 12	0 14 8	1 3 4	1 8 0	1 12 16	2 1 12	2 6 8	2 11 4	3 0 0
7	0 5 12	0 11 4	1 0 16	1 6 8	1 12 0	2 1 12	2 7 4	2 12 16	3 2 8	3 8 0
8	0 6 8	0 12 16	1 3 4	1 9 12	2 0 0	2 6 8	2 12 16	3 3 4	3 9 12	4 0 0
9	0 7 4	0 14 8	1 5 12	1 12 16	2 4 0	2 11 4	3 2 8	3 9 12	4 0 16	4 8 0
10	0 8 0	1 0 0	1 8 0	2 0 0	2 8 0	3 0 0	3 8 0	4 0 0	4 8 0	5 0 0
11	0 8 16	1 1 12	1 10 8	2 3 4	2 12 0	3 4 16	3 13 12	4 6 8	4 15 4	5 8 0
12	0 9 12	1 3 4	1 12 16	2 6 8	3 0 0	3 9 12	4 3 4	4 12 16	5 6 8	6 0 0
13	0 10 8	1 4 16	1 15 4	2 9 12	3 4 0	3 14 8	4 8 16	5 3 4	5 13 12	6 8 0
14	0 11 4	1 6 8	2 1 12	2 12 16	3 8 0	4 3 4	4 14 8	5 9 12	6 4 16	7 0 0
15	0 12 0	1 8 0	2 4 0	3 0 0	3 12 0	4 8 0	5 4 0	6 0 0	6 12 0	7 8 0
16	0 12 16	1 9 12	2 6 8	3 3 4	4 0 0	4 12 16	5 9 12	6 6 8	7 3 4	8 0 0
17	0 13 12	1 11 4	2 8 16	3 6 8	4 4 0	5 1 12	5 15 4	6 12 16	7 10 8	8 8 0
18	0 14 8	1 12 16	2 11 4	3 9 12	4 8 0	5 6 8	6 4 16	7 3 4	8 1 12	9 0 0
19	0 15 4	1 14 8	2 13 12	3 12 16	4 12 0	5 11 4	6 10 8	7 9 12	8 8 16	9 8 0

Cot.	11	12	13	14	15	16	17	18	19
Cot.	C. C. G.	C. C. G.	C. C. G.	C. C. G.	C. C. G.	C. C. G.	C. C. G.	C. C. G.	C. C. G.
1	0 8 16	0 9 12	0 10 8	0 11 4	0 12 0	0 12 16	0 13 12	0 14 8	0 15 4
2	1 1 12	1 3 4	1 4 16	1 6 8	1 8 0	1 9 12	1 11 4	1 12 16	1 14 8
3	1 10 8	1 12 16	1 15 4	2 1 12	2 4 0	2 6 8	2 8 16	2 11 4	2 13 12
4	2 3 4	2 6 8	2 9 12	2 12 16	3 0 0	3 3 4	3 6 8	3 9 12	3 12 16
5	2 12 0	3 0 0	3 4 0	3 8 0	3 12 0	4 0 0	4 4 0	4 8 0	3 12 0
6	3 4 16	3 9 12	3 14 8	4 3 4	4 8 0	4 12 16	5 1 12	5 6 8	5 11 4
7	3 13 12	4 3 4	4 8 16	4 14 8	5 4 0	5 9 12	5 15 4	6 4 16	6 10 8
8	4 6 8	4 12 16	5 3 4	5 9 12	6 0 0	6 6 8	6 12 16	7 3 4	7 9 12
9	4 15 4	5 6 8	5 13 12	6 4 16	6 12 0	7 3 4	7 10 8	8 1 12	8 8 16
10	5 8 0	6 0 0	6 8 0	7 0 0	7 8 0	8 0 0	8 8 0	9 0 0	9 8 0
11	6 0 16	6 9 12	7 2 8	7 11 4	8 4 0	8 12 16	9 5 12	9 14 8	10 7 4
12	6 9 12	7 3 4	7 12 16	8 6 8	9 0 0	9 9 12	10 3 4	10 12 16	11 6 8
13	7 2 8	7 12 16	8 7 4	9 1 12	9 12 0	10 6 8	11 0 16	11 11 4	12 5 12
14	7 11 4	8 6 8	9 1 12	9 12 16	10 8 0	11 3 4	11 14 8	12 9 12	13 4 16
15	8 4 0	9 0 0	9 12 0	10 8 0	11 4 0	12 0 0	12 12 0	13 8 0	14 4 0
16	8 12 16	9 9 12	10 6 8	11 3 4	12 0 0	12 12 16	13 9 12	14 6 8	15 3 4
17	9 5 12	10 3 4	11 0 16	11 14 8	12 12 0	13 9 12	14 7 4	15 4 16	16 2 8
18	9 14 8	10 12 16	11 11 4	12 9 12	13 8 0	14 6 8	15 4 16	16 3 4	17 1 12
19	10 7 4	11 6 8	12 5 12	13 4 16	14 4 0	15 3 4	16 2 8	17 1 12	18 0 16

TABLE O.—(*Continued.*)

Cottahs by Chittacks. (5.)

Chittacks. / Cottahs.	1 Cks. G.	2 Cks. G.	3 Cks. G.	4 Cks. G.	5 Cks. G.	6 Cks. G.	7 Cks. G.	8 Cks. G.	9 Cks. G.	10 Cks. G.	11 Cks. G.	12 Cks. G.	13 Cks. G.	14 Cks. G.	15 Cks. G.
1	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	0 10	0 11	0 12	0 13	0 14	0 15
2	0 2	0 4	0 6	0 8	0 10	0 12	0 14	0 16	0 18	1 0	1 2	1 4	1 6	1 8	1 10
3	0 3	0 6	0 9	0 12	0 15	0 18	1 1	1 4	1 7	1 10	1 13	1 16	1 19	2 2	2 5
4	0 4	0 8	0 12	0 16	1 0	1 4	1 8	1 12	1 16	2 0	2 4	2 8	2 12	2 16	3 0
5	0 5	0 10	0 15	1 0	1 5	1 10	1 15	2 0	2 5	2 10	2 15	3 0	3 5	3 10	3 15
6	0 6	0 12	0 18	1 4	1 10	1 16	2 2	2 8	2 14	3 0	3 6	3 12	3 18	4 4	4 10
7	0 7	0 14	1 1	1 8	1 15	2 2	2 9	2 16	3 3	3 10	3 17	4 4	4 11	4 18	5 5
8	0 8	0 16	1 4	1 12	2 0	2 8	2 16	3 4	3 12	4 0	4 8	4 16	5 4	5 12	6 0
9	0 9	0 18	1 7	1 16	2 5	2 14	3 3	3 12	4 1	4 10	4 19	5 8	5 17	6 6	6 15
10	0 10	1 0	1 10	2 0	2 10	3 0	3 10	4 0	4 10	5 0	5 10	6 0	6 10	7 0	7 10
11	0 11	1 2	1 13	2 4	2 15	3 6	3 17	4 8	4 19	5 10	6 1	6 12	7 3	7 14	8 5
12	0 12	1 4	1 16	2 8	3 0	3 12	4 4	4 16	5 8	6 0	6 12	7 4	7 16	8 8	9 0
13	0 13	1 6	1 19	2 12	3 5	3 18	4 11	5 4	5 17	6 10	7 3	7 16	8 9	9 2	9 15
14	0 14	1 8	2 2	2 16	3 10	4 4	4 18	5 12	6 6	7 0	7 14	8 8	9 2	9 16	10 10
15	0 15	1 10	2 5	3 0	3 15	4 10	5 5	6 0	6 15	7 10	8 5	9 0	9 15	10 10	11 5
16	0 16	1 12	2 8	3 4	4 0	4 16	5 12	6 8	7 4	8 0	8 16	9 12	10 8	11 4	12 0
17	0 17	1 14	2 11	3 8	4 5	5 2	5 19	6 16	7 13	8 10	9 7	10 4	11 1	11 18	12 15
18	0 18	1 16	2 14	3 12	4 10	5 8	6 6	7 4	8 2	9 0	9 18	10 16	11 14	12 12	13 10
19	0 19	1 18	2 17	3 16	4 15	5 14	6 13	7 12	8 11	9 10	10 9	11 8	12 7	13 6	14 5

Chittacks by Chittacks. (6.)

Chittacks. / Chittacks.	1 G. Dec.	2 G. Dec.	3 G. Dec.	4 G. Dec.	5 G. Dec.	6 G. Dec.	7 G. Dec.	8 G. Dec.	9 G. Dec.	10 G. Dec	11 G. Dec	12 G. Dec.	13 G. Dec.	14 G. Dec.	15 G. Dec.
1	0·06	0·12	0·19	0·25	0·31	0·37	0·44	0·50	0·56	0·62	0·69	0·75	0·81	0·87	0·94
2	0·12	0·25	0·37	0·50	0·62	0·75	0·87	1·00	1·12	1·24	1·36	1·50	1·62	1·75	1·87
3	0·19	0·37	0·56	0·75	0·94	1·12	1·31	1·50	1·69	1·88	2·07	2·25	2·44	2·62	2·81
4	0·25	0·50	0·75	1·00	1·25	1·50	1·75	2·00	2·25	2·50	2·75	3·00	3·25	3·50	3·75
5	0·31	0·62	0·94	1·25	1·56	1·87	2·18	2·50	2·81	3·12	3·43	3·75	4·06	4·37	4·69
6	0·37	0·75	1·12	1·50	1·87	2·25	2·62	3·00	3·37	3·74	4·11	4·50	4·87	5·25	5·62
7	0·44	0·87	1·31	1·75	2·19	2·62	3·06	3·50	3·94	4·38	4·82	5·25	5·68	6·12	6·56
8	0·50	1·00	1·50	2·00	2·50	3·00	3·50	4·00	4·50	5·00	5·50	6·00	6·50	7·00	7·50
9	0·56	1·12	1·69	2·25	2·81	3·37	3·93	4·50	5·06	5·62	6·18	6·75	7·31	7·87	8·44
10	0·62	1·25	1·87	2·50	3·12	3·75	4·37	5·00	5·62	6·24	6·86	7·50	8·12	8·74	9·37
11	0·69	1·37	2·06	2·75	3·44	4·12	4·81	5·50	6·19	6·88	7·57	8·25	8·93	9·61	10·31
12	0·75	1·50	2·25	3·00	3·75	4·50	5·25	6·00	6·75	7·50	8·25	9·00	9·75	10·50	11·25
13	0·81	1·62	2·44	3·25	4·06	4·87	5·68	6·50	7·31	8·12	8·93	9·75	10·56	11·37	12·19
14	0·87	1·75	2·62	3·50	4·37	5·25	6·12	7·00	7·87	8·74	9·61	10·50	11·37	12·24	13·12
15	0·94	1·87	2·81	3·75	4·69	5·62	6·56	7·50	8·44	9·37	10·31	11·25	12·19	13·12	14·04

TABLE P.

For Converting Acres into Beegahs of 3025 Square Yards.

ACRES INTO BEEGAHS.

Acres.	0		1		2		3		4		5		6		7		8		9	
	Beegs.	B.	Beegs.	B.	Beegs.	B.	Beegs.	B.	Beegs.	B.	Beegs.	B.	Beegs.	B.	Beegs.	B.	Beegs.	B.	Beegs.	B.
0 to 9	0		1	12	3	4	4	16	6	8	8		9	12	11	4	12	16	14	8
10 ,, 19	16		17	12	19	4	20	16	22	8	24		25	12	27	4	28	16	30	8
20 ,, 29	32		33	12	35	4	36	16	38	8	40		41	12	43	4	44	16	46	8
30 ,, 39	48		49	12	51	4	52	16	54	8	56		57	12	59	4	60	16	62	8
40 ,, 49	64		65	12	67	4	68	16	70	8	72		73	12	75	4	76	16	78	8
50 ,, 59	80		81	12	83	4	84	16	86	8	88		89	12	91	4	92	16	94	8
60 ,, 69	96		97	12	99	4	100	16	102	8	104		105	12	107	4	108	16	110	8
70 ,, 79	112		113	12	115	4	116	16	118	8	120		128	12	123	4	124	16	126	8
80 ,, 89	128		129	12	131	4	132	16	134	8	136		137	12	139	4	140	16	142	8
90 ,, 99	144		145	12	147	4	148	16	150	8	152		153	12	155	4	156	16	158	8
0 ,, 900	000		160		320		480		640		800		960		1120		1280		1440	
1000 ,, 1900	1600		1760		1920		2080		2240		2400		2560		2720		2880		3040	
2000 ,, 2900	3200		3360		3520		3680		3840		4000		4160		4320		4480		4940	
3000 ,, 3900	4800		4960		5120		5280		5440		5600		5760		5920		6080		6240	
4000 ,, 4900	6400		6560		6720		6880		7040		7200		7360		7520		7680		7840	
5000 ,, 5900	8000		8160		8320		8480		8640		8800		8960		9120		9280		9440	
6000 ,, 6900	9600		9760		9920		10080		10240		10400		10560		10720		10880		11040	
7000 ,, 7900	11200		11360		11520		11680		11840		12000		12160		12320		12480		12640	

POLES INTO BEEGAHS.

Poles.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.	B.
0 to 9	0	0	0	0	0	4	0	0	8	0	0	12	0	0	16	0	1	0	0	1	4	0	1	8	0	1	12	0	1	16
10 ,, 19	0	2	0	0	2	4	0	2	8	0	2	12	0	2	16	0	3	0	0	3	4	0	3	8	0	3	12	0	3	16
20 ,, 29	0	4	0	0	4	4	0	4	8	0	4	12	0	4	16	0	5	0	0	5	4	0	5	8	0	5	12	0	5	16
30 ,, 39	0	6	0	0	6	4	0	6	8	0	6	12	0	6	16	0	7	0	0	7	4	0	7	8	0	7	12	0	7	16

ROODS INTO BEEGAHS.

Roods.																														
0 to 3	0	0	0	0	8	0	0	16	0	1	4	0																		

20 Biswansees = 1 Biswah
20 ,, = 1 Beegah = 3025 Square Yards.

TABLE R.

For Converting Beegahs of 3025 Square Yards into Acres.

BEEGAHS INTO ACRES.

Beegahs.	0 Acrs.	0 R.	0 P.	1 Acrs.	1 R.	1 P.	2 Acrs.	2 R.	2 P.	3 Acrs.	3 R.	3 P.	4 Acrs.	4 R.	4 P.	5 Acrs.	5 R.	5 P.	6 Acrs.	6 R.	6 P.	7 Acrs.	7 R.	7 P.	8 Acrs.	8 R.	8 P.	9 Acrs.	9 R.	9 P.
0 to 9	0	0		0	2	20	1	1		1	3	20	2	2		3	0	20	3	3		4	1	20	5	0		5	2	20
10 „ 19	6	1		6	3	20	7	2		8	0	20	8	3		9	1	20	10	0		10	2	20	11	1		11	3	20
20 „ 29	12	2		13	0	20	13	3		14	1	20	15	0		15	2	20	16	1		16	3	20	17	2		18	0	20
30 „ 39	18	3		19	1	20	20	0		20	2	20	21	1		21	3	20	22	2		23	0	20	23	3		24	1	20
40 „ 49	25	0		25	2	20	26	1		26	3	20	27	2		28	0	20	28	3		29	1	20	30	0		30	2	20
50 „ 59	31	1		31	3	20	32	2		33	0	20	33	3		34	1	20	35	0		35	2	20	36	1		36	3	20
60 „ 69	37	2		38	0	20	38	3		39	1	20	40	0		40	2	20	41	1		41	3	20	42	2		43	0	20
70 „ 79	43	3		44	1	20	45	0		45	2	20	46	1		46	3	20	47	2		48	0	20	48	3		49	1	20
80 „ 89	50	0		50	2	20	51	1		51	3	20	52	2		53	0	20	53	3		54	1	20	55	0		55	2	20
90 „ 99	56	1		56	3	20	57	2		58	0	20	58	3		59	1	20	60	0		60	2	20	61	1		61	3	20
100 „ 900	62	0		62	2		125	0		187	2		250	0		312	2		375	0		437	2		500	0		562	2	
1000 „ 1900	625	0		687	2		750	0		812	2		875	0		937	2		1000	0		1062	2		1125	0		1187	2	
2000 „ 2900	1250	0		1312	2		1375	0		1437	2		1500	0		1562	2		1625	0		1687	2		1750	0		1812	2	
3000 „ 3900	1875	0		1937	2		2000	0		2062	2		2125	0		2187	2		2250	0		2312	2		2375	0		2437	2	
4000 „ 4900	2500	0		2562	2		2625	0		2687	2		2750	0		2812	2		2875	0		2937	2		3000	0		3062	2	
5000 „ 5900	3125	0		3187	2		3250	0		3312	2		3375	0		3437	2		3500	0		3562	2		3625	0		3687	2	
6000 „ 6900	3750	0		3812	2		3875	0		3937	2		4000	0		4062	2		4125	0		4187	2		4250	0		4312	2	
7000 „ 7900	4375	0		4437	2		4500	0		4562	2		4625	0		4687	2		4750	0		4812	2		4875	0		4937	2	

BISWAS INTO ROODS AND POLES.

Biswas.	0 Acrs.	0 R.	0 P.	1 Acrs.	1 R.	1 P.	2 Acrs.	2 R.	2 P.	3 Acrs.	3 R.	3 P.	4 Acrs.	4 R.	4 P.	5 Acrs.	5 R.	5 P.	6 Acrs.	6 R.	6 P.	7 Acrs.	7 R.	7 P.	8 Acrs.	8 R.	8 P.	9 Acrs.	9 R.	9 P.
0 to 9	0	0	0	0	0	5	0	0	10	0	0	15	0	0	20	0	0	25	0	0	30	0	0	35	0	1	00	0	1	05
10 „ 19	0	1	10	0	1	15	0	1	20	0	1	25	0	1	30	0	1	35	0	2	00	0	2	05	0	2	10	0	2	15

BISWANSEES INTO POLES.

Biswansees.	0 Acrs.	0 R.	0 P.	1 Acrs.	1 R.	1 P.	2 Acrs.	2 R.	2 P.	3 Acrs.	3 R.	3 P.	4 Acrs.	4 R.	4 P.	5 Acrs.	5 R.	5 P.	6 Acrs.	6 R.	6 P.	7 Acrs.	7 R.	7 P.	8 Acrs.	8 R.	8 P.	9 Acrs.	9 R.	9 P.
0 to 9	0	0	0	0	0	$\frac{1}{4}$	0	0	$\frac{1}{2}$	0	0	$\frac{3}{4}$	0	0	1	0	0	$1\frac{1}{4}$	0	0	$1\frac{1}{2}$	0	0	$1\frac{3}{4}$	0	0	2	0	0	$2\frac{1}{4}$
10 „ 19	0	00	$2\frac{1}{2}$	0	0	$2\frac{3}{4}$	0	0	3	0	0	$3\frac{1}{4}$	0	0	$3\frac{1}{2}$	0	0	$3\frac{3}{4}$	0	0	4	0	2	$4\frac{1}{4}$	0	0	$4\frac{1}{2}$	0	0	$4\frac{3}{4}$

EXPLANATION AND USE OF THE TABLES.

TABLE A.

For Correcting Gunter's Chains of 100 Links.

In the use of chains, they are found to stretch, and unless this quantity is most carefully observed daily by comparison with a standard, all them easurements made will be erroneous, and *in defect* in proportion as the chain is too long. This Table, therefore, gives the equivalent, in links, *to be added* for every inch from one to eleven.

Suppose a chain to have stretched four inches: then for every ten chains measured, in the column of links opposite 10 and under the heading of 4 inches, will be found 5·051, the number of links to be added to bring the chains to their proper standard length and *vice versâ*, for chains too short the same quantity will be *deducted.*

TABLE B.

For Reducing Chains to the Decimal parts of a Mile.

This Table is useful in the protraction of the co-ordinate distances for general maps on the Geographical scale. For plotting the latitude and departure points from the first station in the series, as given in the main Circuit Traverse, the distances require to be divided by 80 for the convenience of scale. By the Table this is avoided, and the chance of error by frequent small divisions obviated. Thus:

To obtain the value of 345 chains in miles and decimals, look for the even tens and hundreds (340) in the top lines of the Table, and for the odd chains (5) in the left hand column at the intersection of these two columns will be found 4·3125, the number of miles sought.

TABLE C.

Showing the length of a Degree, Minute, and second of Latitude and Longitude, for every Degree of the Quadrant, the Compression of the Earth being assumed $\frac{1}{304}$.

This Table (extracted from Boileau's Traverse Tables) is calculated by the Formulæ xliii, page 116, of Mr. F. Baily's Astronomical Tables and Formulæ: the compression of the earth at the poles being assumed $\frac{1}{304}$, and the mean degree of latitude taken at 364547 feet. The first ten degrees of latitude and longitude, and afterwards every fifth degree, were computed by the Formulæ, the intermediate degrees being filled in by interpolation, by differences carried out as far as such could be done. The degrees of latitude are calculated for the latitudes of their middle points: for instance, the degree in the Table on a line with number 27 in the first column, is that degree which extends from latitude 26° 30′ to latitude 27° 30′ and in like manner of the rest. The degrees of longitude are computed for the parallels of latitude expressed by the numbers in the same line, in the column designated "distance from the equator."

The use of this Table is to convert the tabular traverses expressed in units of linear measure into their equivalent values of latitude and longitude *in arc: i.e.*, in degrees, minutes, &c., for that part of the earth's surface to which the traverses belong. For a further description of the use of this Table, see pages 448 to 452.

TABLE D.

For Converting Chains and Links into Feet and Decimals of Feet.

It frequently happens that measurements made in one denomination require to be converted into their equivalents of another denomination: for instance, route surveys are generally measured with instruments registering yards or feet; and circumstances may occur, and do frequently happen, where instruments cannot be readily procured,

which induce the necessity of making all measurements of every kind in one or other of the above denominations. Land surveys are, however, generally made in Gunter's measure, or in links the 1000th part of a furlong; and this is the most convenient of all measures, for determining the acreage of any extent of surface; but for geographical purposes, the standard unit being the English foot, those measurements are most convenient which are made in this denomination, the length of degrees of latitude and longitude being most frequently expressed in tables in feet also. The arrangement of this table (taken from Boileau's Traverse Tables) requires no explanation.

There being two significant figures in the number of chains, the first denoting tens, the second units, the equivalents must be taken out for each separately. Enter the column of chains corresponding to the significant figures in the first part of the table, where it is an exact decimal multiple of that number, or in the first or second part of the table, according as the number of links is more or less than 50. When the whole distance is less than 10 chains, the first part of the equivalent value is found in the same column under the number of chains, and in a line with the number of links in the column so designated; the last part of the equivalent is found in the column headed decimals of feet, of which there is one for each part of the table. The decimal parts are taken out as whole numbers, removing the decimal point in the equivalent number as many places as it is removed in the original. Given the length of a line in a survey 47 ch. 25·6 links, required its equivalent in feet and decimals.

Ch.	Lks.	Ft.	Dec.
40		2640	
7	25	478	·50
	·6		·396
47	25·6	3118	·896 feet.

Table E.

Atmospherical Refractions.

This Table from the Nautical Almanac of 1826, is computed upon principles explained by Dr. Young in the Philosophical Transactions for 1819; and it appears to agree more perfectly with the latest observations than any other table that has been published. The formula employed is

$$\cdot 0002825 = v\,\frac{r}{s} + (2\cdot 47 + \cdot 5\,v^2)\,\frac{r^2}{s^2} + 3600\,v\,\frac{r^3}{s^3} + 3600\,(1\cdot 235 + \cdot 25\,v^2)\,\frac{r^4}{s^4};$$

r being the fraction, v the sine of the altitude, and s the cosine.

The apparent altitude being found in the first column, the second shows the refraction when the barometer stands at 30 inches, which is its mean height at the level of the sea, and the thermometer at 50° of Fahrenheit. The third column contains the difference to be subtracted or added for every minute of altitude, reckoned from the nearest number in the first column. The fourth shows the number of seconds to be added for every inch that the height of the barometer exceeds 30°, or to be subtracted for each inch that it wants of 30°; and the last contains the number of seconds to be subtracted for each degree that the thermometer stands above 50°, or to be added for each degree that its height wants of 50°.

If great accuracy be required, we must also deduct from the observed height of the barometer ·003 in. for each degree that the thermometer near it is above 50°, and add an equal quantity for an equal depression. In fact, however, the table, as it now stands, is found to require the temperature to be estimated from the height of the thermometer within, and if we employed the height of the thermometer without, which would be more consistent with the theory, it would probably be necessary to suppose the standard temperature of the table 48° only, instead of 50°.

Examples.

1. At 7°. 18′. 13″ Bar. 29·87 Ther. 66°, the Refr. is 6′. 52″, 26, from 22 obs. of Bradley.
2. At 19°. 18′. 19″ Bar. 30·045 Ther. 34°, the Refr. is 2′. 51″, 5, from 3 obs. of Bradley.
3. At 13°. 43′. Bar. 29·85 Ther. 45°, the Refr. is 3′. 55″, 85, from 156 obs. of Mr. Pond.

1. Alt. 7°. 20′	R. 7′ 8″	Diff. Alt.		″·9	B. 14″·3	Th. ″·93
	+ 1·62	1′ 47″ =		1′. 8	—·13	—16
	7· 9·62		+	1·62	1·86	14·88
	16·74					1·86
	6. 52·88					16·74
	6· 52·26					
Error............	0·62					
2. Alt. 19°	R. 2′ 47″·7	Diff· Alt.		″·16	B. 5″·61	Th. ″·34
	—2·93	18′ 19″ =		18·3	+ ·045	+ 16
	2· 44·77		—	2·93	·252	5·44
	·25					
	5·44					
Error	1″,02·50·46					
3. Alt. 13°. 40′	R. 3′ 55″·5	Diff. Alt.		″·29	B. 7″·89	Th. ″·482
	+ ·36			3	·15	5
	3· 55·86		—	·87	— 1·18	+ 2·41
	3· 55·85				·87	2·05
Error............	·01				2·05	+ ·36

Table F.

Parallax of the Sun.

This Table contains the Parallax of the Sun at different degrees of altitude above the horizon, and for different months of the year. To find the Parallax for 44 degrees of altitude for the month of April, look in the column of altitude for 44°, and on a line with it, and under the column containing the month will be found the parallax, *viz.*, 6″·33 always *additive* to the altitude. (From Bagay's Tables.)

Table G.

For Reversing Angles.

Errors will often occur in reversing the inward or outward angles of a circuit survey. By this table the complement of the angle, or what it wants of 360°, can be obtained without the necessity of subtraction. The two upper lines of the table contain the *minutes*, as well as *seconds*, and the remaining columns the *degrees* from 0 to 179 in the left hand divisions, and from 180 to 359 in the right hand divisions of the columns.

To obtain the complement of an angle subtending 348° 14′, under 14 in the line of minutes is 46, and in the left division on a line with 348 in the column of degrees is 11. The complement of the angle is therefore 11° 46′.

It seldom happens that observations are taken to full degrees, but in cases where there are no minutes, it will be necessary to add 1° to the number taken from the table. Thus: the complement of an angle subtending 115° will be 244° by the table, to which add 1°, will give 245°, the complement required.

Table H.

Comparative scale of Fahrenheit's, Reaumur's and the Centigrade Thermometers (from Boileau's Tables) for determining the altitude of mountains.

Equivalents to Fahrenheit's Thermometer in Reaumur's and the Centigrade Scales.

The Temperatures of the Freezing and Boiling points by the several Thermometers are as follows:—

By Fahrenheit's scale,	Freezing point	32°,	Boiling point	212°
„ Reaumur's	ditto	„	0	„	80
„ Centigrade	ditto	„	0	„	100

Let $x°$ denote any degree in Fahrenheit's scale; its value in the other denominations will be expressed by the following Equations:—

$$x° \text{ Fahrenheit} = (x°-32) \times \tfrac{4}{9} \ldots\ldots\ldots \text{ Reaumur.}$$

$$\text{„} \quad \text{„} \quad = (x°-32) \times \tfrac{5}{9} \ldots\ldots\ldots \text{ Centigrade.}$$

by which Formulæ this Table has been computed.

When the number given is a whole degree Faht. the Equivalent in Degrees of Reaumur and the Centigrade scale is found in the proper column, and in the same horizontal line with the given degree Faht.; but when the given number contains the decimal of a degree, the Equivalent for the part must be found by proportion.

Example.—Required the degree of the Centigrade Thermometer corresponding to 206°·3 Faht.

206°	Faht.	... ...	=	96°·67	Centigrade.
·3	„	= ·55 + $\frac{3}{10}$	=	·16	„
206°·3	Faht.		=	96°·83	Centigrade.

The number ·55 is the difference between the equivalents in Centigrade degrees, to 206° and 207° Faht.

In taking out the differences from the columns of equivalents for fractions of degrees Faht. between 32° and 0°, the given degree Faht. and the one next less must be employed, as the corresponding values of Reaumur's and the Centigrade scales increase negatively below 32° Faht.

Tables I and J.

For Converting Intervals of Sidereal Time into equivalent Intervals of Mean Solar Time, and vice versâ.

The tables of time equivalents are useful for converting mean solar into sidereal time, and sidereal into mean time, agreeably to the example annexed to each table. They will serve, also, for tables of acceleration and retardation, by taking the difference between each argument and its equivalent. Thus in table J, the *excess* of the sidereal time equivalents above the arguments of mean time show *acceleration* of sidereal or mean solar intervals, and in table I the *defect* of the mean time equivalents, as compared with the arguments of sidereal time, indicate the retardation of mean on sidereal intervals.

These tables, with the above explanation, are given from the Nautical Almanac.

Table K.

Showing the Correction to be applied to a Barometer with a brass scale, extending from the cistern to the top of the mercurial column, to reduce the Observation to 32° Fahrenheit.

The observed height of a Barometer, taken at different temperatures before they can be compared with each other, will require reduction to one common temperature. The reduc-

tion consists of two parts, one part being due to the dilation of the mercury, and the other to that of the brass scale attached to the Barometer: both these corrections are embodied in the following formula :—

$$C = B.\frac{(t - 32^\circ)\,m - (t - 62^\circ)\,b}{1 + (t - 32^\circ)\,m}$$

$C =$ Sum of the two corrections.

$B =$ Observed height of the Barometer.

$t = \left\{ \text{Observed temperature of the mercury and of the brass scale, which are assumed to be equal.} \right.$

$m =$ ·000100 expansion of mercury for 1° of Fahrenheit.

$b =$ ·0000106 ditto of brass ditto ditto.

32° Standard temperature of mercury.

62° Ditto, ditto of brass.

By the aid of this formula this table has been computed, which, as it is specially intended for the reduction of the Meteorological Observations taken at the Surveyor-General's Office and used for the Printed Monthly Register, is limited to the range of the atmospherical pressure and temperature which occur in Calcutta; the former extending from inches 28·1 to 30·4, and the latter from 50° to 100° Fahrenheit. More general tables on the subject will be found in the Admiralty Manual of Scientific Enquiry, page 319—the Corps Papers of the Royal Engineers—and Boileau's Tables, 1849.

The arrangement and use of this Table will be best understood from the following example :—

Suppose it is required to compute the correction for Barometer 29·780 inches and Thermometer 83°·3.

The Tabular number for 29·8 inches and 83° Fahrenheit	·145
Alteration for 0°3 Fahrenheit, deduced by the common rule of proportion ...	·001
Required correction	·146
Observed height of the Barometer	29·780
Height reduced to 32° Fahrenheit...	29·634

It will be remembered that the Tabular correction is always *negative.*

Tables L, M, and N.

For Converting Acres into Beegahs of 1,600 *square yards, and* vice versâ, *also for converting the Decimal part of an Acre or Bengal Beegah into its corresponding value of Roods and Poles, or Cottahs and Chittacks.*

The explanation of these tables is given at the foot of each table, with examples.

Table O.

Table of Square Measure.

This table will be found useful in the khusrah measurements, for checking the multiplications of the sides of fields to obtain the contents. The mode of using it, together with an example, is given at the head of the table.

Tables P and R.

For Converting Acres into Beegahs of 3,025 *square yards, and* vice versâ.

These tables are calculated in the same manner as tables L, M, and N, and are made use of in a similar manner.

ON THE CONVERGENCY OF MERIDIANS BY MAJOR R. SHORTREDE.

To find in Minutes the Convergency of two Meridians in any Latitude, and at any distance apart in miles or chains.

For departure in Miles.		For departure in Chains.	
To the const. log.	9·9388	To the const. log.	8·0357
Add log. tan. lat.	...	Add log. tan. lat.	...
And log. departure in miles ...	...	And log. departure in chains ...	...
The sum is log. conv.	...	The sum is log. conv.	...

When a main circuit is plotted, commencing from a *Thoka*, or Boundary mark, or Survey Station, whose co-ordinates are known, the approximate co-ordinates of any other point in the circuit may be found by scale to within a few chains of the truth, and much nearer than is indispensable for finding the convergency.

The annexed table shews the convergency on 100 miles, and on 1000 chains of departure for each degree of latitude in the Punjab, or from 29° to 36°.

Lat	Convergency on 100 Miles.	Convergency on 1000 Chains.	Lat.	Convergency on 100 Miles	Convergency on 1000 Chains.
29°	48′·143	6′·018	33°	56′·404	7′·050
30	50·145	6·268	34	58·584	7·323
31	52·187	6·523	35	60·824	7·603
32	54·272	6·784	36	63·103	7·888

To find the constant Logarithms given above.

Mean radius of the Earth in miles, 3958·06 &c.	log.	3·5974822
are equal to radius 3437·747	„	3·5362739
1 Geographical Minute = 1·15155225 miles	„	0·0612083
1 Mile = 0·8685434 geogr. min. const.	„	9·9387917
= 80 Chains	„	1·9030900
For chains const. log.		8·0357017

For Mean Radius of the Earth.

Equatorial Radius in feet 20921665*	log.	7·320	5962	438
		7·320	5962	438
Polar Radius „ 20852394*	log.	7·319	1559	222
		21·960	3484	098
Mean Radius in feet	log.	7·320	1161	366
1 Mile = 5280 feet		3·722	6339	225
Mean Radius in miles 3958·06 &c.	log.	3·597	4822	141

* De Morgan, as in last page of Shortrede's Logarithms.

Using Everest's first set, as given in the Trigonometrical Survey Table, we have—

Equatorial Radius $a = 20922931{\cdot}80$ feet... ...	log.	7·320	6225	895
		7·320	6225	895
Polar Radius $b = 20853374{\cdot}58$	log.	7·319	1763	443
		21·960	4214	283
Mean Radius in feet	log.	7·320	1404	744
		8·722	6339	225
Mean Radius in miles 3958·28	log.	8·597	5065	519
Difference of elements 0·22		0·000	0243	378
		9·938	7917	
G. T. S. Const. for miles ...		9·938	8160	

Extract from the Handbook of Circular Orders and Instructions of the Revenue Survey Department of India.

OBSERVED AND DEDUCED AZIMUTHS AND CORRECTION FOR CONVERGENCY.

Observed, reduced, and deduced azimuths.

In the revenue survey there are three *so-called* values of the azimuth of the line between an observed station and the station of observation. First, *the observed* azimuth, as given by astronomical observations. Second, this observed azimuth *reduced* to the meridian of the origin of the survey, by the application of the correction for convergency. Third, the azimuth *deduced* by the continual addition of the angle used in the traverse computations, to the initial azimuth, or that observed at the origin of the survey.

Though the terms "*Observed Azimuth*," "*Reduced Azimuth*," and "*Deduced Azimuth*" are commonly employed, yet it is only the first expression that gives a correct and clear notion of the direction of the line in question; for the azimuth of a line is the angle it makes with the meridian of the point from which it is drawn, not its angle with any other meridian, and therefore, when it is referred to any other meridian, the use of the word azimuth is incorrect, and liable to mislead. The so-called *reduced* azimuth is in reality the true inclination of the said line to the meridian of the origin, and the *deduced* azimuth is the computed value of the inclination of the said line to the meridian of the origin as deduced from the traverse computation.

Introduction of reduced azimuths into traverse tables.

If the difference on comparison of "*Deduced*" with "*Reduced*" azimuths be not greater than 2 minutes, the angles and bearings of the traverse may be left as originally entered: but if it be *more than* 2 *minutes*, correction must be applied, and in this case the *reduced* azimuthal value of the line shall be at once introduced into the traverse computations, and the angular work be corrected to bring out this new value.* When the difference between the "*Deduced*" and the "*Reduced*" azimuths is so large as to create doubts of the correctness of the angular work, the angles must of course be re-observed.

Entry required on traverse forms at azimuth stations.

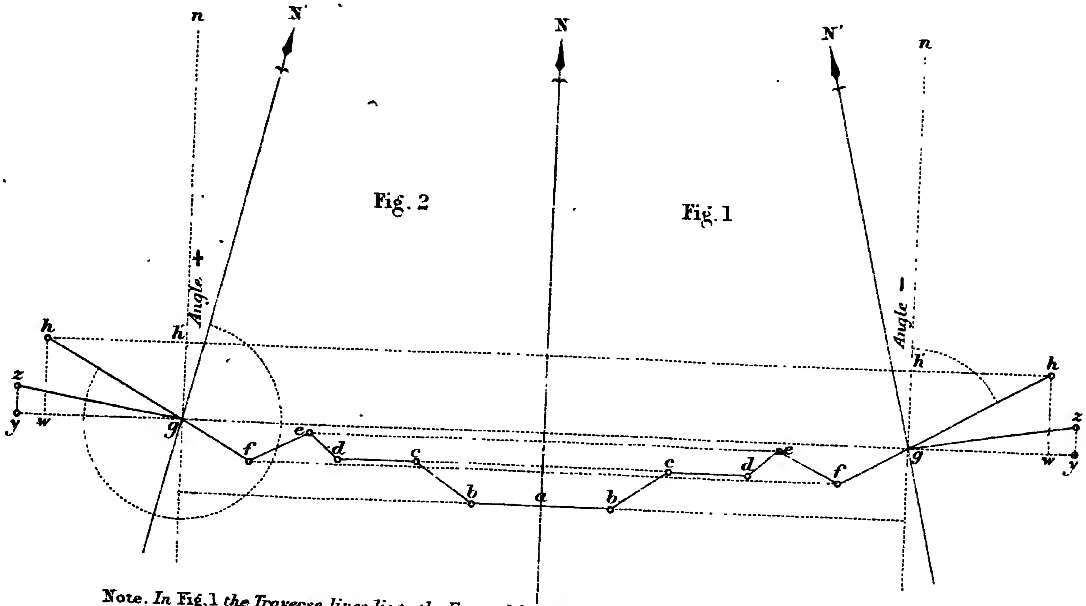
The following entry should be made on main circuit traverse tables forwarded to the head-quarters' office, and recorded in red ink alongside each station where an azimuth has been observed:—

I.—The observed azimuth.

II.—The correction for convergency.

III.—The reduced bearing, or inclination to initial meridian.

☛ An illustration in explanation of the rule for applying corrections for convergency of meridians follows.



Note. *In* Fig. 1 *the Traverse lines lie to the East of the Meridian of origin and the angle N'gn is subtractive from the angle N'gh, to obtain the true angle for Traverse computation, ngh, Similarly, if the Traverse lines run to the West of the Meridian of origin, the angle N'gn becomes additive as shown in* Fig. 2.

ILLUSTRATION OF THE RULE FOR APPLYING CORRECTION FOR CONVERGENCY OF MERIDIAN.

Let a be the starting point of a survey, *vide* Plate XXII (facing), where the azimuth of origin has been laid down, and to which it is necessary to refer all other points connected with the survey operations, in order to preserve their relative positions by the application of the traverse system of rectangular co-ordinates, drawn respectively parallel and perpendicular to the meridian of the origin.

Suppose the survey to proceed along the lines ab—fg to the station g, where, owing to the distance traversed, and the number of angles observed between it and the first station, it becomes necessary to check the work by re-observation of azimuth; suppose the azimuth of the forward line gh to have been observed and to be represented by the angle $N'\,gh$.

Draw $g\ n$ parallel to $a\ N$, and it is obvious that the inclination of the meridian $g\ N'$ to that of $a\ N$ is measured by the angle $N'\,g\ n$.

To obtain the true position of the point h by co-ordinates measured from the point a, it is clear we must ascertain the value of the departure $h'h = gw$ and of the perpendicular $h'g = hw$; these values added to the co-ordinates already obtained by traverse for g, will give those of h, and the distances so obtained, being plotted from the meridian $a\ N$ will give the point h correctly on the map. Now to obtain these co-ordinates we require to know the angle $h'gh$ which is equal to the angle $N'gh$, less the angle of convergency $N'gn$, which measures the inclination of the two meridians $a\ N$ and $g\ N'$.

Let us however suppose that in lieu of using the above corrected angle, or *reduced* azimuth, which, if the angular work had been good, would be nearly the same as that *deduced* by traverse, we had used the *observed* azimuth of the lines $g\ h$,—*i.e.*, the angle $N'\,g\ h$, and see what the result will be.

At g lay off the angle $n\ g\ z$ = the *observed* azimuth $N'\,g\ h$, and make $g\ z$ = the measured distance $g\ h$; draw $z\ y$ perpendicular to $g\ w$ produced. If now we add the quantities $z\ y$, $g\ y$ respectively, to the corresponding co-ordinates of the point g, already *deduced* by traverse, we find that by thus using the *observed* azimuth $N'\,g\ h$, instead of the *reduced* azimuth ngh the point h is brought down to z, or very much too far to the south.

The error thus shown to be engendered through the use of *observed* azimuths, instead of *reduced ones*, is not the only one that may arise; for it is clear that the value of the angle $N'gn$ which measures the convergency of the two meridians, if brought into the traverse computation, must affect some one or more of the bearings of the lines between the point g and the starting point a, and will in like manner, if neglected, throw all stations affected thereby too much to the south.

This may be practically shown by computing out a traverse with *observed* and also with *reduced* azimuths, the results will show at a glance what serious discrepancies may be caused by the use of *observed* instead of *reduced* azimuths, and that when the *observed* azimuths are used, an enormous correction is required to make the easting and westing agree; but, on the other hand, when convergency has been allowed for, and the so-called *reduced* azimuths or true inclinations with the meridian of the origin are employed, the corrections are small, and much more in accordance with the known accuracy of the angular and chain measurements.

Good field work has often been converted into bad mapping in consequence of the mistakes which have been made on this point. It would be far better that surveyors, who feel a difficulty in getting a clear conception of the subject, should make no use of these *observed* azimuths of verification, but simply carry on their work by the continual addition of the angles of the traverse to the initial azimuth at the origin of their survey, rather than run the risk of distorting their maps, and introducing large errors in their efforts to eliminate small ones.

TO FIND THE TRUE MERIDIAN.

If we observe the pole-star at any part of its course, and know also how much it is then to the east or west of the meridian, we have only to apply that quantity to the observed position.

The azimuth motion of the pole-star, though always slow when compared with that of most other stars, varies considerably; for any place in India its azimuth, when on the meridian, varies by nearly one minute of space in two minutes of time; and when at its elongation it varies less than 1′ in half an hour: hence, when the azimuth is observed near the elongation, it is of no great importance to know the time very exactly.

In the revenue survey an error of 1′ in azimuth is of little importance, and therefore if we can find any simple means of making sure that the pole-star is within half an hour of its elongation, we may get an observation sufficiently correct for the purpose of the survey.

The two brightest stars in the heavens are Sirius and Canopus. Sirius is easily recognized by its lustre, and by its being to the left of the easily known constellation of Orion. Canopus is the bright star nearly south of Sirius, and about 36° distant.

When these two stars have the same azimuth $\left\{\begin{matrix}6^\circ \text{ to } 7^\circ \\ \text{W. of S.}\end{matrix}\right\}$ (which is easily known by the eye or by a plummet, or by a vertical staff, &c.) the pole-star is within half an hour of its western elongation, and for at least three quarters of an hour its azimuth will not vary so much as 1′ (one minute of space).

The eastern elongation may also be known readily enough, though the mark is not quite so good.

The bright star Vega comes to the meridian about half an hour before the elongation, and the less bright star Attair (nearly midway between two smaller ones) comes to the meridian about forty minutes after the elongation.

Hence the eastern elongation may be observed at any time after Vega has passed the meridian and before Attair has reached it.

In the Panjab, Vega passes the meridian a few degrees to the north of the zenith, and Attair at from about 20° to 25° to the south.

Throughout the greater part of the year one elongation occurs during the night, and the other during the day. It is only for a few days that both elongations can be observed on the same day.

The eastern elongation occurs during the night throughout the greater part of the recess, or from April 7 till October 11, when observations are not much wanted.

Throughout the greater part of the field season, or from October 11 till April 7, the western elongation is available, and for the purposes of the survey it is the only one of much importance.

DIRECTIONS FOR OBSERVING AN AZIMUTH.

When the Theodolite has been set up at a station and levelled, it should be carefully adjusted immediately before the observations.

The referring mark and the star should then be observed alternately twice over, beginning and ending with the referring mark: then turn the instrument half round in azimuth, reverse the vertical arc, and observe again as before, mark-star, star-mark.

At each observation all the verniers should be read and noted.

The time by watch is to be noted at each observation of Polaris, and if a watch be not used, an altitude of a star for time must be observed in the middle of each set. This altitude should be true to within 10′, which will give the time true to less than a minute.

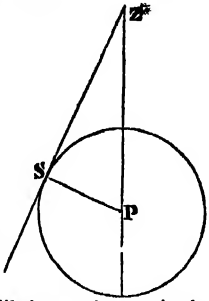
By observing in this way, the result is freed from errors of collimation and of horizontal axis.

When properly observed, the means of the pairs of readings should differ very little, and if this be not the case it would be well to take another set.

From the mean of the readings of the referring mark subtract the mean of the readings of the star, and when $\left\{\begin{matrix}\text{W. subtract}\\ \text{E. add}\end{matrix}\right\}$ the star's elongation; the result is the true azimuth of the referring mark.

Then according as the place of observation is to the east or west of the origin, subtract or add the convergency, found as above, and the result is the working azimuth referred to the meridian of the origin.

To find for any Latitude the greatest Elongation of a Star.



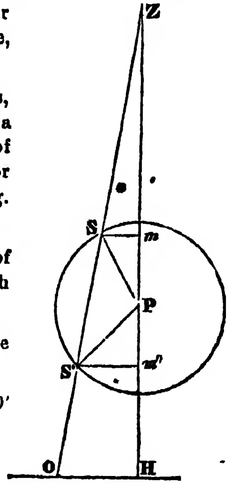
In the adjacent figure Z is the zenith, P the pole, and S the star.

Rule.		Example.	
To the log. sec. lat ...	... Lat.	32°.20	sec. 0.07317
Add log. sin. pol. dist ...	... P. S.	1°.29	sin. 8·41307
The sum is log. sin. elong	P. Z. S.	1°.45′.20″	sin. 8·48624

In the Punjab the elongation varies by about half a minute for a degree of latitude, and every year the polar distance diminishes by nearly one-third of a minute, and the elongation by about three-eighths of a minute.

The method above explained, though probably the one least likely to miscarry in the hands of a novice, has the inconvenience of requiring the observer to be out of bed in the middle of the night during the cold season. This may be avoided, and the observations may be taken in the evening, when convenient, if by means of a watch, or an altitude of some proper star, we can find how far the pole-star is past the meridian at the time of observation.

To find the Azimuth of the Pole-Star in a given Latitude, knowing its hour angle, and polar distance.



In the adjacent figure, Z being the zenith, P the pole, S the star and $H\ O$ the horizon, $H\ P$ is the latitude, $P\ S$ the polar distance, and $Z\ P\ S$ the hour angle.

Having reduced the polar distance to minutes and hundredths, with $P\ S$ as a distance, and $P\ Z\ S$ as a bearing, find as in a common traverse, the co-ordinates $P\ m\ S\ m$. The altitude of the star $O\ S = H\ m = H\ P \pm P\ m$, according as S is above or below P, then log. $P\ S$ + log. sin. $Z\ P\ S$ + log. sec. $H\ m$ = log. Azimuth.*

The time may be found by an altitude between 10° and 30° of some well-known star, whose declination is under 30°, or if a watch be used its error may be found by an altitude of the sun.

An error of 1 minute in time, or 15′ on $Z\ P\ S$ will never make 30″ error in the azimuth.

The following observations were made at Zaferwál, lat. 32° 20′ N. lon. 75° E. = 5h, on the 9th of April, 1852:—

	h. m. s.			
The Sun's alt. was observed at	6. 01. 53	lower limb	3.° 48	R
	6. 04. 25	upper limb	3. 53	L
Time by Watch ...	6. 03. 09	Sun's alt ...	3. 51. 30	

* This method, though not quite rigorous is, quite sufficient for the purpose.

And afterwards, Polaris and a referring mark, thus:—

Face, Object, and Time.	Readings.			Mean.	General Means.
	A.	B.	C.	° ′ ″	° ′ ″
Referring Mark ...	206. 32½	29½	31½	206. 31. 10	206. 30. 35
W. 11·41. 40 ...	272. 46	45	48	272. 46. 20	272. 46. 50
11· 44. 00 ...	272. 47	46	49	272. 47. 20	293. 43. 45
Referring Mark ...	206. 31	28	31	206. 30. 00	11h. 42′ 50″
Referring Mark ...	26. 27½	30	31	26. 29. 30	26. 29. 40
E. 11·57. 50 ...	92. 53½	55	52	92. 53. 30	92. 54. 20
12· 02 20 ...	92. 55	56	54½	92. 55. 10	293. 35. 20
Referring Mark ...	26. 27	31	31½	26. 29. 50	12h. 00′ 05′

	Time.	Apparent Azimuth.	
	h. m. s.	° ′ ″	
	11. 42. 50	293. 43. 45	F. W.
	12. 00. 05	293. 35. 20	F. E.
Mean of Polaris Observations ...	11. 51. 27·5	293. 39. 32·5	
Sun's alt. observed at	6. 03. 09		
Interval in mean time	5. 48. 18·5		
Acceleration in interval at 9·857 per hour ...	57·34	Watch supposed to be going true mean time.	
Interval in sidereal time	5. 49. 15·84	Between observations of sun and star.	

Calculation for Time, and for Polaris Hour Angle.

	h. m. s.		° ′ ″		
	6· 03· 09	⊙App. Alt ..	3. 51. 30		This is the same for sun or star.
		Refr. ...	— 12. 30		
		⊙Tr. Alt. ...	3. 39		
		Alt.........	32. 20	Sec. ... 0·07317	
Dec............	7° 45′ N.	⊙N.P.D. ...	87. 15	Cosec.. 0·00399	
		Sum.......	118. 14		
	h. m. s.				
Watch.........	6. 03. 09	½ Sum.......	59. 07	Cos. ... 9·71036	
Mean time....	6. 03. 49	½ Sum. Alt.	55. 28	Sin. ... 9·91582	
Watch slow on mean time ...	0. 40	App. Time	6. 02. 19	S. vers. 9·70334	
		Equation	+ 1. 30	9·85167 *S. m.*	45° 17′ 23″
		Mean time	6. 03. 49		90. 34. 46
					6. 02. 19
		Long. E.	5.		
Greenwich mean time			1. 03. 49		

(NAII)	☉ R at Gr. M. Noon	1.18. 01. 68
	Increase in 1. 08. 49.	9. 75
	☉ R at time of Observation	1.18. 11. 43
	☉ Hour angle W	+6.02. 19.
	Meridian R at time of Observation	7.15. 30. 43
	Sidereal interval between Observations	5.49. 15. 84
	Sidereal time of observation, Polaris	13.04. 46. 27
	Polaris R	1.04. 49. 65
	Polaris Hour Angle	11.59. 56. 62

Polaris was thus only 3″·38 from the lower transit; its azimuth was 1″53 W. This taken from 293° 39′ 32″·5 gives 293°39′ 31″ as the *true* azimuth of the referring mark, from which, deducting 18½ for convergency, there remains 293° 21′ as the *working* azimuth.

The Hour Angle of Polaris is got more readily when, for each face, time is found by a star altitude taken between the observations of Polaris: thus, in the case of Sirius W, 5h. 02′ 19″, the work would be—

	h.	m.	s.
Sirius R	6.	38.	37
H. Angle Sirius	5.	0.2	19 + W — E
Mer. R	11.	40.	56
Polaris R	1.	04.	50
Polaris Hour Angle	{ 10. 159°.	36. 01′.	06 = 30″

MEMORANDUM ON THE MUSEUM OF ECONOMIC GEOLOGY OF INDIA.

The objects of the Museum of Economic Geology of India, which has been established by Government at Calcutta, under orders from the Honourable the Court of Directors, in conjunction with the Asiatic Society and at its rooms, are the following:—They are, as scientific men will perceive, generally those of Economic Geologists in all countries; but there are some peculiarities connected with India and the situations of Europeans in it, which will oblige us to go into a little detail, to explain to those who may not already take an interest in these matters, our wants, our wishes, and our hopes of the advantages which may accrue to the community from this new establishment. Its objects, then, are briefly these—

1.—To obtain the most complete Geological, Mineralogical, and Statistical knowledge possible of all the mineral resources of India, wrought or unwrought, so as to make them as publicly known as possible; to show how they have been or are now wrought, or how they might be so to the best advantage.

2.—To obtain a complete set of specimens, models and drawings, relative to the Mining operations, Metallurgical processes, and Mineral manufactures, of all kinds of India, and of Europe and America, so as to afford to the public information of everything which can be turned to account here or in Europe, and perhaps prevent loss of time, waste of capital, and disappointment to the Indian speculator.

3.—To furnish the Engineer and Architect with a complete collection of all the materials, natural or artificial, which are now, or have formerly been, used for buildings,

cements, roads, &c., and all of which *may* possibly be used in this department, whether European or Indian.

4.—To collect for the Agriculturist specimens of all kinds of soils remakable for their good or bad qualities, with the subsoil, subjacent rocks, &c., and by examination of these to indicate their various peculiarities, and the remedies for their defects.

5.—To collect for Medical men the waters of mineral springs, and mineral drugs, &c.

6.—And finally, by chemical examinations of all these various specimens, to determine their value, and how they may be best turned to account for the general benefit of the community.

With objects like these, the Museum of Economic Geology may be said to be placed between the purely scientific geologist and the merchant, the miner, the farmer, the manufacturer, and the builder, or in other words, the merely practical men, who may desire to know how the knowledge of the geologist and mineralogist—to them often so recondite, and apparently so useless—can forward their views; and its office to be, if possible, to answer all questions of this nature which may arise for public benefit.

This may sometimes be done from books, but the great library must be the collections of our Museum, which are in fact a library of examples, to which the commentary is the laboratory, where, aided by the resources of the collection, questions may often be solved in an hour, a day, or a week, which it would take half an *Indian* life to obtain the mere materials for investigating. An extensive collection, then, is the first requisite, and this should, if possible, comprise every inorganic product of the earth from which mankind derive any advantage, with every information relative to it. It will readily occur to the reader, that in India, owing to her infancy in some of the arts dependent on these products, as in mining, agriculture, &c., and her singular progress in others, as in peculiar branches of metallurgy and the like, our almost absolute ignorance of what her methods and resources are, the peculiarities of situation in which these resources may exist, those of climate, workmen, and many others, we have almost everything yet to learn; and that to accomplish our objects, we cannot be too well furnished with all the knowledge and examples of Europe and the Americas, and all those of India or of Asia. Without these our progress must be very limited; but in proportion as we obtain them, we may hope, without presumption, to see the day when the mines, the quarries, and the soil of India, may be done justice to, which assuredly has never yet been the case.* In this, all classes are so clearly interested, that it would be superfluous to show it, as it is to show that the resources of every country are far more readily developed with public means for investigating, preserving, and publishing all knowledge belonging to them, than where none such exist.

It is therefore hoped, that those who may be desirous of assisting this great public work will bear in mind that nothing, however familiar it may be to those on the spot, is indifferent to us; *for if not wanted for the institution, it may serve to procure that which is*; and the following note is given rather as a general memorandum, than as specifying all which is desired. The general rule is, that details cannot be too numerous, nor specimens too various, particularly if purely Indian.

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* It is curious to find that upwards of 140 years ago the ores of the precious metals were an article of export from the Dutch East Indies. This is clearly shown by the following passage from Solhutter's work, as translated by Hellot, and published by him under the title of "Hellot sur les Mines," Paris, 1753. In vol. II, p. 285, chap. xlvi "*On East Indian Ores, and their Fusion by the Curved furnace,*" he says:—

"In 1704, Solhutter received by a private channel twenty-five quintals of ore from the East Indies, &c." And again: "These sorts of ores (of gold and silver) sent from India by the Dutch, were frequently smelted at the foundry of Altenau in the Upper Harts, but had never been smelted in the Lower Harts. This ore was in lumps from the size of a nut to that of walnut, and by trials it was found that the quintal of 110 lbs. contained 1 oz. 8 drs. of gold, and 3½ oz. of silver."

DESIDERATA FOR THE MUSEUM OF ECONOMIC GEOLOGY OF INDIA.

I.—Mines and Mining Products.

1.—Specimens of all crude ores, just as found. If possible, also of the rocks or matrix in which found; of those indicating the vein at the surface; of the walls of the veins; of the strata of beds passed through before reaching them; and of the rocks of the surrounding country.

2.—The ores after preparation for the furnace, by picking, washing, stamping, roasting, &c.

3.—The rejected ores, gravel or stones found with those used, which often go under odd names, as those of "mother," "devil," or the like.

4.—The fluxes used, if any.

5.—Memorandum of the kind of fuel used, samples of it if coal or coke, &c.; names of the trees, as bamboo, &c.; if charcoal, and if not too far, send specimens.

6.—The roasted or half-smelted ore.

7.—The pure metals, as obtained in a merchantable state, of all the qualities.

8.—The slags of all kinds, from the furnaces and smeltings.

9.—Drawings or models (to scale if possible) of all furnaces, machinery, and implements used in any of the processes, with drawings, plans, and models of the mine. Earthen models of the furnaces, &c., may often be well made by the native image makers for a mere trifle.

10.—Specimens of any tools used.

11.—Traditions, history, and statistics of the mine or mineral products: as (1) How and when found; (2) Produce, gross and net; (3) Rent, if farmed, or what tax payable on the product; (4) Price of daily labour; (5) Amount of labour obtainable for a given price; (6) Estimated profits, past and present; (7) Reasons for decay or increase; (8) What is now required to make the mine more productive; (9) Copies or notices of any books or accounts of the mine; (10) Health, comfort, morals, and condition of the workmen employed, average of ages, and if life among them is thought unhealthy; seasons and hours of work. Superstitious notions, peculiar diseases, &c., &c.

II.—Buildings, Cements, Pottery, Colours, Roads, &c.

1.—Specimens from the quarries, of all kinds of building stones, useful, or merely ornamental.

2.—The same of limestones, shells, corals, or other articles used to make lime or cements of all kinds.

3.—Specimens of the strata above and below the quarried stone.

4.—Any fossil shells, bones, fish, plants, insects, or other appearances of organic remains, large or small, found in or near the quarries, or amongst the rubbish and water-courses of quarried spots. If specimens appear too large to move, please to give a notice with an eye-sketch and estimate of the expense of moving, and preserve it till a reply is sent.

5.—Specimens of the building stones or remarkable bricks used in any public edifices, monuments or tombs, with the date of their erection, if known, and a note to say if exposed to weather, or protected by stucco, paint, or roofs.

6.—Memoranda and specimens of any plants or animals destructive to masonry, as boring worms and shells in water, and the like, with specimens of their work.

7.—Ornamental or stucco work; specimens of it, new or old, interior or exterior, with the best account procurable of the materials, preparations, and working of them.

8.—Specimens of stones and marbles, shells, &c., used for image or ornament-making; of earths for pottery, and varnishes of coloured earths of all sorts, whether used as pigments or not.

9.—Specimens of peculiarly good materials used for roads, whether ancient or modern, with prices, methods of using them, and other memoranda.

10.—Prices of all the above, rates of labour, carriage, &c., from the rough to the wrought state, and all other statistical details, as in the case of Mines and Mineral products above-mentioned.

III.—Agricultural Geology.

1.—Specimens of soils of good and the best qualities, for all kinds of produce, as sugar, cotton, tobacco, &c.

2.—Of infertile soils or veins of earth.

3.—Of the subsoil or rock.

4.—Of the stones scattered about these soils.

5.—Memoranda relative to the height of these soils above the water of wells in the rains and dry seasons, and of its drainage, shelter, exposition, &c.

6.—Of any kind of earths, mud, or stones used as manures, as peats from the jheels, kunkurs, &c.

7.—Of the deposits (fertile and infertile) left either by the common inundations or by violent floods, with memoranda of their effects on the cultivated soil.

8.—Specimens from any separate spots where gravel or stones are collected in quantities after inundations or floods.

9.—Accounts of remarkable floods, and average heights of the rise of rivers, of the raising of the soil, alterations in its produce consequent thereupon, and all other details.

10.—Memoranda relative to the formation or destruction of river-banks, islands, &c. with measurement, if obtainable.

11.—Samples of all kinds of efflorescent salt-earths, with specimens of the different salts prepared from them, prices of preparation, selling rates, and accounts of the processes and uses of the salts.

12.—Specimens of brine-springs, with details of manufacture if boiled for salt, and statistics of labour and produce, &c., as in the case of mines.

IV.—Medical Geology.

1.—Specimens of mineral medicines of all sorts, whether produced on the spot, or imported, crude and prepared, with notes and samples of the process of preparation in all its stages.

2.—Of the water of mineral springs, their temperature, incrustations about them, account of their uses, and specimens of the rocks or soil in which found.

V.—Native Metallurgical Processes, or Mineral Manufactures.

1.—Exact descriptions of them, however rude or simple they may appear, with samples of the ores, fuel, fluxes, products, slags, &c.

2.—Models or drawings (to scale if possible) of the furnaces and implements of all kinds; specimens of these last may be sent.

3.—Memoranda and samples of the earths or sands used for moulds in castings, of the crucibles and beds, raw and baked, and of the raw material from which made.

4.—Prices of raw and wrought materials.

5.—Drawings of machinery used for turning, boring, polishing, &c.

In conclusion: it is not supposed that any individual, unless wholly devoted to the research, can supply the whole of the desired specimens, or even of the knowledge relative to any one product; but any *single* item of the foregoing may be of importance, at some time, to some one; and it will be the special duty of the Asiatic Society, and of the Curator of the Museum, to see justice done to every contribution, whether relating to the Geology of India in general, or to this peculiar branch of it.

(Signed) H. PIDDINGTON,
Curator, Museum Economic Geology.

MEMORANDUM OF INSTRUCTIONS FOR APPLICANTS FOR THE TOPOGRAPHICAL, AND REVENUE BRANCHES OF THE SURVEY DEPARTMENT OF INDIA.

1st.—Every applicant for the Survey Department of India must present his application in person to the Surveyor-General, Deputy Surveyor-General or Superintendent of Revenue Surveys, or to any Officer of the Survey Department authorized by them to examine the candidate. If after due enquiry the canditate is likely to prove a suitable person in every respect for the Department, he may be admitted to examination if vacancies exist, but the Surveyor-General cannot undertake to examine every person who applies, or to record every application made.

2nd.—A statement must be furnished shewing the age of the candidate, and his previous employment or occupation, if any.

3rd.—Also as to his general education, religion and parentage, (European or East Indian), name and occupation of his father.

4th.—A medical certificate of sound and perfect health and eye sight, and physical fitness for the arduous duties of a Surveyor's life in the field.

5th.—Certificates from School or College, testifying to good conduct and sound morals, and a certificate from some respectable gentleman or responsible Government Officer, regarding the candidate's respectability.

6th.—Every candidate must have passed his 18th year, and no married person, or person likely soon to be married, will be admitted.

7th.—Candidates must be prepared, and state readiness, to pass the full examination in every subject, and will have to submit specimens of Topographical or map drawing; a good taste for which is indispensable.

8th.—Every passed candidate will be required to enter into a Bond (as on the other side) to serve the Government for three years, under a penalty of the forfeiture of one-half of the whole amount actually received in the shape of salary. He must also undertake never to demand his discharge *during the Field Season.* This agreement is strictly enforced in all cases.

9th.—Qualified candidates may be appointed as "Assistant Surveyors" on Rs. 120 per mensem with three rupees field or travelling allowance whilst employed in the field, or else as "Sub-Surveyors," on Rs. 40, rising to Rs. 70, with three-tenths of salary as travelling allowance, according to special aptitude and qualifications and as vacancies may exist.

10th.—A few apprentices are likewise occasionally entertained, to do duty at Head Quarters, pending vacancies, but in all cases the examination must be passed.

SUBJECTS OF EXAMINATION AND MAXIMUM NUMBER OF MARKS FOR EACH.

		Marks. Maximum.
ARITHMETIC.	Vulgar and Decimal Fractions, and Mensuration and Proportion.	200
	Square and Cube Roots, and Ditto by Logarithms.	50
	Total.	250
ALGEBRA.	Surds.	50
	Binomial Theorem.	50
	Arithmetical Progression.	50
	Geometrical Progression.	50
	Simple Equations, Simultaneous Equations and Problems.	80
	Quadratic Equations, Simultaneous Equations and Problems.	100
	Total.	380
GEOMETRY.	Six Books Euclid.	100
	Problems in Ditto.	100
	Total.	200
2ND PART OF MATHEMATICS.	Analytical Plane Trigonometry as far as the Solution of Triangles.	100
	Logarithms, Numbers.	50
	Ditto Sines and Tangents.	30
	Heights and Distances.	100
	Total.	280
WRITING AND DRAWING.	Hand Writing and Writing from Dictation.	100
	Military or Topographical Drawing.	100
	Map and Plan Drawing.	100
	Freehand Drawing.	30
	Hand Printing or Map Writing.	60
	Total.	390
	Grand Total.	1500

N. B.—Three-fourths of the total number of marks must be obtained for a successful examination.

The same Rules apply to the Great Trigonometrical Survey, but with a somewhat higher standard in Mathematics and the addition of Spherical Trigonometry.

(Signed) H. L. THUILLIER, *Col.*,

Surveyor-General of India.

SURVEYOR-GENERAL'S OFFICE,
Calcutta, 1st January 1872.

AGREEMENT of ______________________________

Assistant Surveyor in the ______________________ *Survey of India.*

I ______________________________ do hereby, of my own free will and accord, engage upon my honor to serve Her Majesty's Indian Government in the capacity of Assistant Surveyor, for the space of *three years* from the date specified in the margin, during which period I declare that I will perform with zeal, fidelity and to the utmost of my abilities the duties that may be entrusted to me; that I will obey all such lawful orders, as I may, from time to time, receive from those who are duly placed in authority over me; and that I will abide by, and conform to, all the regulations at present in force respecting the Survey Establishment, on consideration of receiving a monthly salary as therein established; and in case of my being desirous at any time during the period intervening between the ____________ day of ____________ One thousand eight hundred and ____________ and the ____________ day of ____________ One thousand eight hundred and ____________ to obtain a release from this my engagement, I do agree upon my honor to repay to Her Majesty's Indian Government a sum equal to one-half of the whole amount, which I may actually have received in the shape of Salary or Allowance of any kind between the dates aforesaid, in furtherance and confirmation of which stipulation, I do hereby fully and entirely relinquish all claim or pretentions to be absolved from this my engagement, until a sum equal to the amount aforesaid shall have been previously deposited by me, in the hands of Agents duly authorized by the Surveyor-General of India (or Deputy Surveyor-General), to receive the same. In witness of which agreement, I hereunto set my hand this ____________ day of ____________ in the year of our Lord One thousand eight hundred and ____________

____

____

Witness to the above Signature

____

____

Done this ____________ day of ____________ at the Office of the ______________________ One thousand eight hundred and ____________ before me

____

____

SCALE OF SALARIES SANCTIONED BY GOVERNMENT FOR THE JUNIOR ESTABLISHMENT, SURVEY DEPARTMENT OF INDIA.

		Per mensem				
Surveyor ...	1st grade	Rs. 500,	with	field allowance	of Rs. 4 per diem	while under canvas.
Do.	2nd do.	Rs. 400	do.	do.	of Rs. 3 per diem	do.
Do.	3rd do.	Rs. 350	do.	do.	of Rs. 3 per diem	do.
Do.	4th do.	Rs. 300	do.	do.	of Rs. 3 per diem	do.
Asst. Surveyor,	1st do.	Rs. 250	do.	do.	of Rs. 3 per diem	do.
Do.	2nd do.	Rs. 200	do.	do.	of Rs. 3 per diem	do.
Do.	3rd do.	Rs. 160	do.	do.	of Rs. 3 per diem	do.
Do.	4th do.	Rs. 120	do.	do.	of Rs. 3 per diem	do.

Sub-Surveyors on Rs. 40, rising to Rs. 70, with three-tenths of salary per mensem field allowance.

Table for computing Subtended Angles to assist in the Computation of Heights, by Captain George Strahan, R.E.

(See Explanation on the following page.)

	0′	1′	2′	3′	4′	5′	6′	7′	8′	9′
0″	0·000	4·147	4·448	4·624	4·749	4·846	4·925	4·992	5·050	5·101
1″	2·369	154	451	626	751	847	926	993	051	102
2″	670	161	455	629	752	849	927	994	052	102
3″	846	168	458	631	754	850	928	995	052	103
4″	971	175	462	633	756	851	930	996	053	104
5″	3·067	181	465	636	758	853	931	997	054	105
6″	147	188	469	638	759	854	932	998	055	106
7″	214	195	472	640	761	856	933	999	056	107
8″	272	201	476	643	763	857	934	5·000	057	107
9″	323	207	479	645	765	858	936	001	058	108
10″	3·369	4·214	4·482	4·647	4·766	4·860	4·937	5·002	5·059	5·109
11″	410	220	486	650	768	861	938	003	060	110
12″	448	226	489	652	770	863	939	004	061	110
13″	482	232	492	654	772	864	940	005	661	111
14″	515	238	496	656	773	865	941	006	062	112
15″	545	244	499	659	775	867	943	007	063	113
16″	573	249	502	661	777	868	944	008	064	114
17″	599	255	505	663	778	870	945	009	065	114
18″	624	261	508	665	780	871	946	010	066	115
19″	647	266	512	667	782	872	947	011	067	116
20″	3·670	4·272	4·515	4·670	4·783	4·874	4·948	5·012	5·067	5·117
21″	691	277	518	672	785	875	949	013	068	117
22″	711	282	521	674	787	876	951	014	069	118
23″	730	288	524	676	788	878	952	015	070	119
24″	749	293	527	678	790	879	953	016	071	120
25″	766	298	530	680	792	880	954	017	072	121
26″	783	303	533	682	793	882	955	018	073	121
27″	800	308	536	684	795	883	956	019	074	122
28″	816	313	539	687	797	884	957	020	074	123
29″	831	318	542	689	798	886	958	021	075	124
30″	3·846	4·323	4·545	4·691	4·800	4·887	4·960	5·022	5·076	5·124
31″	860	328	518	693	802	888	961	023	077	125
32″	874	332	550	695	803	890	962	024	078	126
33″	887	337	553	697	805	891	963	025	079	127
34″	900	342	556	699	806	892	964	026	079	127
35″	913	346	559	701	808	894	965	027	080	128
36″	925	351	562	703	809	895	966	027	081	129
37″	937	355	564	705	811	896	967	028	082	130
38″	948	360	567	707	813	897	968	029	083	131
39″	960	364	570	709	814	899	969	030	084	131
40″	3·971	4·369	4·573	4·711	4·816	4·900	4·971	5·031	5·085	5·132
41″	981	373	575	713	817	901	972	032	085	133
42″	992	377	578	715	819	903	973	033	086	133
43″	4·002	381	581	717	820	904	974	034	087	134
44″	012	386	583	719	822	905	975	035	088	135
45″	022	390	586	721	823	906	976	036	089	136
46″	031	394	589	723	825	908	977	037	089	136
47″	041	398	591	725	826	909	978	038	090	137
48″	050	402	594	726	828	910	979	039	091	138
49″	059	406	596	728	829	911	980	040	092	139
50″	4·067	4·410	4·599	4·730	4·831	4·913	4·981	5·041	5·093	5·139
51″	076	414	601	732	832	914	982	042	094	140
52″	085	418	604	734	834	915	983	042	094	141
53″	093	422	607	736	835	916	984	043	095	142
54″	101	425	609	738	837	918	986	044	096	142
55″	109	429	612	740	838	919	987	045	097	143
56″	117	433	614	741	840	920	988	046	098	144
57″	124	437	616	743	841	921	989	047	098	144
58″	132	440	619	745	843	922	990	048	099	145
59″	[illegible]	444	621	747	844	924	991	049	100	146
60″	4·147	4·448	4·624	4·749	4·846	4·925	4·992	5·050	5·101	5·147

Explanation.

It generally happens that, in determining the heights of intersected points, reciprocal observations are not forthcoming. The object of this Table is to determine the subtended angle from the one observed vertical angle with the least possible unnecessary work.

To use the Table proceed as follows:—

Look through the column for the number nearest to the first four figures of the log base in feet. Then the number standing at the head of the column in which it occurs is the number of minutes, and the number in the first column on the same horizontal line is the number of seconds, to be added to an observed elevation, or subtracted from an observed depression, to give the subtended angle.

Example.—Let log base = 4·7915328, and the observed vertical angle = depression 0° 17′ 9.″

The nearest number to the log base is 4·792, the number at the top of the column in which 4·792 occurs is 4′, and the number in the first column on the left on the same horizontal line is 25″.

	°	′	″
Hence Observed Depression	0	17	9
Subtract		4	25
Subtended Angle	0	12	44

Therefore it is unnecessary to know either the contained arc or the vertical angle at the intersected point.

The subtended angle being known, the difference of heights may be computed as follows. Difference of height = base augmented × tan subtended angle.

The usual formula is difference of heights = base (augmented) × sin subtended angle × sec B.

The difference between these two is unimportant in the computation of heights of intersected points.

The Table is computed for latitude 26°, and assumes the refraction to be $\frac{1}{15}$th of contained arc, but the latitude affects it very little, and the Table may be safely used for intersected points for 3 or 4 degrees on either side of 26°. The principle of it is as follows:—

Let the subtended angle be denoted ... ... by S
„ Depression at the known station A ... by A
„ at B (unknown) ... ... by B
„ contained arc ... ... by c
„ the base in feet ... ... by a
„ the refraction ... ... by R
„ rad. of earth at Station A ... ... by $\frac{2\rho\nu}{\rho+\nu}$

$$\text{Then } R = \frac{c-A-B}{2} = \frac{c}{15} \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$S = \frac{A-B}{2} \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

From (1) $B = c - A - 2R$

Substituting this value of B in (2) and reducing we have $S = A + R - \frac{c}{2}$

For R substitute $\frac{c}{15}$

Then $S = A - \frac{13}{30}c = A - \cdot433 \times c$

But $c = a \times \frac{\text{cosec } 1'' \, (\rho + \nu)}{2 \rho \nu}$

$\therefore S = A - \frac{\cdot433 \text{ cosec } 1'' \, (\rho + \nu)}{2 \rho \nu} \times a$

The term $\frac{\cdot433 \text{ cosec } 1'' \, (\rho + \nu)}{2 \rho \nu}$ is tabulated with the assistance of Table V of the Auxiliary Tables, G. T. Survey.

Tables to Convert Feet into Miles, and vice versa, without the use of Log Tables.

The following Tables are very simple, and have been very successfully used by Native surveyors for whom they were originally computed and tabulated by Mr. N. A. Belletty, Surveyor, Topographical Survey Department.

The following examples fully explain their use and application.

Example.—Required the miles corresponding to 76,735 feet.

From Table I.—In the first column marked feet is given 70,000, then run horizontally along this line, and stop at the column containing 6,000; or at 14·3939, which is the equivalent in miles of 76,000 feet.

Similarly, find the equivalent for 730 from Table II, and for 5 from Table III thus:—

	Feet.		Miles.
	76,000	=	14·3939
+	735	=	0·1383
+	5	=	·0010
	76,735	=	14·5332

Example.—Required the miles corresponding to 156,845 feet.

Now 156,845 = (99,000 + 57,845), and by finding the equivalents in miles of 99,000 and 57,845 the miles corresponding to 156,845 feet can be obtained: proceeding in the same way as given in Example A:—

	Feet.		Miles.	
From Table I	99,000	=	18·7500	
	57,000	=	10·7955	
„ Table II	840	=	0·1591	
Table III	5	=	·0010	
	156,845	=	29·7056	Miles required.

Tables for Converting Feet into Miles.

Table I.

Nos.	0,000	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000
		0·1894	0·3788	0·5682	0·7576	0·9470	1·1364	1·3258	1·5152	1·7046
10,000	1·8939	2·0833	2·2727	2·4621	2·6515	2·8409	3·0303	3·2197	3·4091	3·5985
20,000	3·7879	3·9773	4·1667	4·3561	4·5455	4·7349	4·9242	5·1136	5·3030	5·4924
30,000	5·6818	5·8712	6·0606	6·2500	6·4394	6·6288	6·8182	7·0076	7·1970	7·3864
40,000	7·5758	7·7652	7·9545	8·1439	8·3333	8·5227	8·7121	8·9015	9·0909	9·2803
50,000	9·4697	9·6591	9·8485	10·0379	10·2273	10·4166	10·6061	10·7955	10·9849	11·1742
60,000	11·3636	11·5530	11·7424	11·9318	12·1212	12·3105	12·5000	12·6894	12·8788	13·0682
70,000	13·2576	13·4470	13·6364	13·8258	14·0152	14·2044	14·3939	14·5833	14·7727	14·9621
80,000	15·1515	15·3409	15·5303	15·7197	15·9091	16·0983	16·2879	16·4773	16·6667	16·8561
90,000	17·0455	17·2348	17·4242	17·6136	17·8030	17·9922	18·1818	18·3712	18·5606	18·7500

Table II.

	0	10	20	30	40	50	60	70	80	90
0	......	·0019	·0038	·0057	·0076	·0095	·0114	·0133	·0152	·0170
100	·0189	·0208	·0227	·0246	·0265	·0284	·0303	·0322	·0341	·0360
200	·0379	·0398	·0417	·0436	·0455	·0473	·0492	·0511	·0530	·0549
300	·0568	·0587	·0606	·0625	·0645	·0663	·0682	·0701	·0720	0739
400	·0758	·0777	·0795	·0814	·0833	·0852	·0871	·0890	·0909	·0928
500	·0947	·0966	·0985	·1004	·1023	·1042	·1061	·1080	·1098	·1117
600	·1136	·1155	·1174	·119[illegible]	·1212	·1231	·1250	·1269	·1288	·1307
700	·1326	·1345	·1364	·1383	·1402	·1421	·1440	·1459	·1478	·1497
800	·1515	·1534	·1553	·1572	·1591	·1610	·1629	·1648	·1667	·1686
900	·1704	·1723	·1742	·1761	·1780	·1799	·1818	·1837	·1856	·1875

Table III.

Units.		
1	=	·0002
2	=	·0004
3	=	·0006
4	=	·0008
5	=	·0010
6	=	·0011
7	=	·0013
8	=	·0015
9	=	·0017

MEMORANDA

FOR

LEVELLING OPERATIONS

IN CONNECTION WITH

THE GREAT TRIGONOMETRICAL SURVEY OF INDIA.

BY COLONEL J. T. WALKER, R.E.

The following memoranda, which were drawn up for the guidance of the officers who are employed in the Levelling Operations of the Great Trigonometrical Survey of India, are now printed under the expectation that they may be of service to officers of other Departments who are engaged in similar operations. Though originally intended to regulate the procedure to be followed in the execution of lines of levels which are of such enormous extent that it is imperatively necessary to take every possible precaution against all the several sources of error which are liable to impair the accuracy of the results, they contain suggestions which it is believed may be followed with advantage in operations of less extent, where a less careful and precise system of observation will suffice to secure as much accuracy as is desirable.

The memoranda are divided into three sections, of which the first has reference to the prevention of accidental gross errors, such as are caused by erroneous readings of the staves, by the deflection of the staves from the perpendicular, and by inaccuracies in the adjustments of the levelling instruments. The second indicates the precautions which must be taken to guard against minute cumulative errors of all kinds, the causes of which may be personal, instrumental, or atmospheric. The third contains general observations on the determination of the units of the staves, on instrumental adjustments, &c.

In determining how far it may be desirable to follow the system of the Trigonometrical Survey in operations which do not require an equal degree of precision and refinement, it is necessary to consider the several kinds of error, proceeding in succession from those which have the greatest to those which have the smallest effect on the accuracy of the results.

First—Errors of Staff Readings.

These I believe are the chief cause of the inaccuracies so frequently met with at the close of a line of levels, which often necessitate the repetition of the operations. Even when an observer is careful to repeat his readings at each station before proceeding to the next, he may occasionally make a mistake without finding it out; the causes which led him to make an erroneous reading in the first instance, are very liable to influence him to repeat the mistake at the second reading, if they are still in operation.

In order to guard against such influences, the staves of the Trigonometrical Survey are graduated on opposite faces, one face being painted white with black divisions in feet,

tenths, and hundredths, from 0 to 10 feet, the other face being painted black with white divisions, also in feet, tenths and hundredths, but numbering from 5·55 at bottom to 15·55 at top. Thus any two corresponding readings on the opposite faces have a constant difference of 5·55, and there is nothing to bias the observer to make the same error in a reading on one face that he may have made on the other. It is customary to take two pairs of readings to the back and forward staves, one pair on their white faces, the other pair on their black faces; the two values of the resulting difference of level from each pair of readings to the two staves should coincide, and if they do not do so it is at once seen that a mistake has been made, which must be immediately ascertained and rectified. The double readings and record necessarily take more time at the moment than single readings of staves graduated on one face only, but they are twice as valuable, and in the long run they will probably save time by eliminating errors which would vitiate the operation and require it to be done over again.

I therefore strongly advocate the employment, in all levelling operations, of staves divided on both faces as are those of the Trigonometrical Survey. They are a great assistance to the observer, and go far to prevent the possibility of any gross error of reading taking place, without being at once discovered.

SECOND—ERRORS OF THE PERMANENT INSTRUMENTAL ADJUSTMENTS.

It is well known that these errors, as well as those which might be caused by normal atmospheric refraction and the earth's curvature, are wholly eliminated when the staves are placed at equal distances from the instrument. If the ground will not allow of the instrument being put midway on the line between the staves, by shifting the position of the instrument and the forward staff, some point can always be found where the instrument will occupy the vertex of an isosceles triangle, of which the line between the staves is the base. Unequal distances should always be avoided if possible; there is no excuse for them excepting on unusually rough ground, when the observer is pressed for time, and then the distances should be made as short as possible. All distances should be fairly well measured either with a chain, or a subtense instrument.

THIRD—ERRORS CAUSED BY INSTRUMENTAL DEFLECTION FROM HORIZONTALITY.

In the operations of the Trigonometrical Survey the instruments are approximately levelled, then the scale readings of the ends of the bubble are read and recorded, and a correction for instrumental dislevelment is applied to the difference of level deduced from the staff readings. A convenient method of determining the value of the run of the level, and the usual process of applying corrections for dislevelment, are described in the Appendix. I believe that the accuracy of the results fully repays the trouble of the calculations. This procedure may, however, be dispensed with, when great accuracy is not wanted, by invariably bringing the bubble into the middle of the scale before taking a staff reading, or by making the bubble occupy the same position when the telescope is pointed to the forward staff as it occupied when the telescope was pointed to the back staff. The levels of ordinary instruments are not supplied with scales, they usually have a couple of notches merely to indicate the position into which the bubble should be brought; consequently in extreme temperatures the ends of the bubble are frequently so far from the notches, either within or beyond them, that there is much difficulty in bringing the bubble into the desired position. It is therefore advisable to construct a paper scale and attach it to the tube of the level as an aid to the observer in bringing the bubble into position; for this purpose a scale in which there are 20 to 30 divisions to the inch will be found convenient; the numbering of the divisions should be carried from the centre outwards.

Fourth—Minute Cumulative Errors.

These may be eliminated to a considerable extent by alternating the order of observations to the back and forward staves at the successive stations, observing the back staff first at one station and the forward staff first at the next. The two staves should be read in as rapid succession as is possible without impairing the accuracy of the observations; a long interval should never be allowed to elapse between the readings, and the instrument should be screened from the sun's rays during the observations.

The forward staff at one station ought invariably to be used as the back staff at the next station, in order that its zero error may be eliminated. The operations might advance more rapidly if the staff carriers moved simultaneously with the observer—as is not uncommonly done in practice,—but the difference of level deduced at each station would be erroneous by the difference between the zero errors of the two staves, the effect of the error would be constant, and the cumulative effect on a long line of operations might be very considerable.

The suggestions contained in these memoranda have no claim to originality, though some of them may be novel even to persons who have long been employed in executing levelling operations. The purpose for which they are now published will be fully answered if they induce any person to endeavour to improve the accuracy and value of his levels by the adoption of some of the precautions against error which have been found indispensably necessary in the execution of the long lines of levels of the Trigonometrical Survey of India, and which have indisputably enhanced in no small degree the value of the results of those operations.

The projected lines of levels of the G. T. S. are of the immense length. Their only extraneous source of verification is the sea level. The shortest line from sea to sea will be upwards of 1,500 miles long, and other lines will probably be 1,000 miles longer. Hence the necessity for the utmost possible precaution in guarding against accidental gross errors, and against the accumulation of small errors, to which operations conducted with the greatest refinement and delicacy seem to be liable, as is apparent in our line of levels, 960 miles long, from Karrachee to Attock, as well as in that executed by Mr. Bunt, under the superintendence of Professor Whewell, for the Royal Society of England, These Memoranda are intended to embody, in a few rules for future guidance, the experience hitherto acquired in levelling operations.

1st.—To Guard against Accidental Gross Errors.

(A.) Our staves are graduated on both sides, one face being painted white, with black divisions, and divided from 0 to 10·00 feet; the other face being black, with white divisions, divided from 5·55 to 15·55. Thus the corresponding readings on the two faces of a staff have a constant difference of 5·55, and if an observer make a mistake in one reading, he is not likely to make a similar mistake in the reading on the opposite face, and the error will be shown up immediately by the different results from black and white faces, if the computations be correctly performed. Errors of reading are, however, of such uncommon occurrence, and the results from black and white faces so constantly coincide, that the observer in writing down the second result immediately under the first is liable to be biased by it, and to fancy they coincide, when, in reality, there is a difference. On a single line of levels such a mistake by an observer working alone might not be discovered until the preparation of the duplicate records months afterwards, when the mistake could no longer be corrected. Hence the necessity for employing a second observer, with an independent set of instruments, to go over the line, station by station, after the first. There is thus a surer guarantee against oversights and other errors, as well as those of reading, and a corresponding relief of

the anxiety a single leveller must experience when working for months without knowing whether his results are accurate or not.

(B.) The staves should invariably be set up at equal distances from the instrument, in order to cancel all errors arising from the necessarily more or less imperfect adjustment of the level to the optical axis of the telescope. The distances should be carefully measured with a chain. In some treatises on levelling, unequal distances are recommended, when convenient, provided the precaution be taken of counteracting the error thus introduced at one station, by similarly uneqal distances at the next, placing the instrument as far from the back staff at the 2nd station as it was from the forward staff at the 1st. This method, though sometimes convenient, is not necessary, as our own experience in levelling over several hundred miles of hilly ground sufficiently shows. It should not be resorted to, because, when the distances are unequal, refocussing becomes necessary between the back and forward observations, and there is a risk of disturbing the visual axis, the permanence of which during a pair of observations is imperative.

(C.) The values of the spirit levels must be determined if possible on the vertical arc of a great theodolite, or other well graduated vertical circle; or by setting up a staff at a convenient distance, and measuring thereon the subtense of 1 division of the scale of the level. Either method will give the requisite data for the construction of a Table of Subtenses, which should extend continuously by half-tenths of a division of scale from 0·05 to 5·00, and for successive distances of whole chains from 1 to 10.

The observer, having levelled his instrument closely, must record the bubble end readings at each observation, and deduce from them the error of position of the level, *i.e.*, the dislevelment, the corresponding correction for which will be found in the Subtense Table.

(D.) The staff readings should be taken to 3 decimal places; when the staves are very close, a 4th place of decimals might be estimated on them, but this is so rarely the case that it may be treated as exceptional, and need not require us to extend our observations beyond the 3rd place, which is the farthest that can be used with satisfaction. It should therefore be the limit to which to carry the Table of Subtenses, and all calculations of mean results.

(E.) At least two pairs of observations at each station are necessary, one between the black faces, the other between the white. The observations of the back and forward staves should follow each other as quickly as possible consistent with accuracy, in order that they may be strictly differential. If the two results agree within ·006, and the observer is otherwise satisfied with them, he should proceed to the next station. If they differ by a greater amount, they should be repeated once or twice, according to discretion. If the differences are very large, and obviously due to grazing rays, the station should be rejected, and a better one selected instead, if possible. In choosing his staves at the commencement of field operations, the observer must remember to examine the differences between the zeros of the black and white faces of each staff. In most of our staves it is 5·55, but in some of the new ones it is 5·60. Both of a pair should have the same difference in common, otherwise the observer will be perplexed and delayed by troublesome discrepancies between the results from black and white faces.

(F.) The staves must invariably rest on wooden pins driven very firmly into the ground. A hemispherical brass brad should be let into the head of each pin after it is driven, to offer a point, instead of an uncertain surface, for the staves to stand on, that they may be rotated freely, and each face presented in succession to the observer. The brad also affords a common point of reference for the successive observers, whose results may thus be compared rigorously station by station.

(G.) The staves are supplied with plummets let into their sides, and visible through glass doors. They may thus be adjusted with certainty to within an inch or two of the true perpendicular. They are held in position by ropes attached to a swivel on their summits. When a staff has once been set up and observed, it should not be readjusted if it has to be observed at the next station, when the difference of level is small, because then any error caused at the first station by the deflection of the staff will be in great measure cancelled at the next. The staff should however be carefully readjusted whenever, having been read near the bottom at one station, it is liable to be read near the top at the next.

(H.) Each day's work will necessarily close more frequently on the temporary pins over which the line of levels is carried, than on permanent bench-marks. The closing station must therefore be relevelled next morning, to test the permanence of the pins, before carrying on operations beyond them.

2nd.—To Guard against Cumulative Errors.

These are caused by the constant recurrence of small errors, either personal, instrumental, or atmospheric; which, though too minute to attract notice at any one station, become manifest when the results of different observers on the same line of levels are compared, or those of a single observer returning station by station over a line from terminus to origin.

(I.) Errors recurring in a constant order, such as might be caused by working with a uniformly rising or uniformly sinking refraction, or by a tendency in the instrument to settle on its axis more one way than another on being set up for observation, may be cancelled by Colonel Waugh's system of alternating observations, which is to observe the back staff first at alternate stations, and the forward staff first at the intermediate stations. This method may be still farther amplified by the following circuit system, by which an observer working in only one direction has the means of finding whether there are such errors in his work, by comparing the differences between the respective reductions to origin from the black and white faces, one pair of which may be treated so as to give the results of an "up line," and the other of a "down line":—

Odd Stations ...	1	Forward Staff Back ,,	White faces. Down line.
	2	Back ,, Forward ,,	Black faces. Up line.
Even Stations, ...	1	Back Staff Forward ,,	Black faces. Up line.
	2	Forward ,, Back ,,	White faces. Down line.

(J.) Errors may recur in a constant order if there is any irregularity in the chamber of the axis, and it is invariably set up in one direction. Droop might thus be caused in a constant direction. Obviate this by marking one of the legs, either of the tripod stand or of the instrument, and directing it alternately back and forward at alternate stations. The marked leg will thus invariably point to the same staff holder throughout the whole of a section, so there will be no difficulty in remembering the order of alternation.

(K.) The circuit system which requires an observer to close on his origin is theoretically the best. It was adopted on the line of levels executed in England for the Royal Society. This however was only 100 miles long, whereas the lines of the G. T. Survey must average 2,000 miles in length from sea to sea.

A circuit is exposed to a greater chance of accidental error when levelled by a single observer, than a single line executed by two levellers working consecutively and independently. For both to work twice over the same line would more than double the time and

cost of the undertaking, as they would never be able to increase the distances of the staves from the instrument, when favored by clear weather, but would be compelled to adopt short unvarying distances. Fortunately if, in a long line of operations, an amount of extra trouble equivalent to marching once over the whole line be accepted, all the advantages of closing on origin may be obtained by the simple expedient of dividing the line into equal sections, and working alternate sections in opposite directions. If the sections are no longer than a day's work—in good ground 4 miles—and circumstances will permit of encamping near their extremities, it is easy to walk 4 miles to the commencement of a section without fatigue in the early morning before sunrise, and then level the 4 miles back to camp, whereby the delay of the extra marching is avoided, and steady progress made at a rapid rate. This circuit system has apparently contributed more than anything else to reduce cumulative differences in our operations, and it should be invariably adopted.

(L.) In our levels from the sea to Attock, a tendency was observed for the — corrections to exceed the + very considerably while we were working from south to north, and *vice versa* the + exceeded the — corrections when working from north to south. It is of importance to have as many + as — corrections, for they thus cancel each other, and any small error in the determination of the runs of the levels is thus eliminated. Accumulation of level error must therefore be guarded against. At each station the algebraical mean value of all the corrections for that station should be determined, and entered with its proper sign into the column for that purpose in the Field Book. These should be summed up algebraically as the work proceeds, that the observer may be prepared to prevent a preponderance in any one direction, by setting up his instrument with a slight tilt in the opposite direction.

(M.) The last precaution may be considered more troublesome than valuable, but of this and other similar calculations connected with these operations, as determining the cumulative difference between black and white faces, &c., it will be found that they may be done by inspection by the observer or recorder, while walking with the Field Book in his hand from station to station. They are only troublesome when neglected for some time, and then they are more curious than useful in checking cumulative error.

3rd.—General Observations.

(N.) The units of the levelling staves must be determined in terms of the 10-foot standard of the G. T. Survey. For this purpose a portable metal bar, on which the length of the standard bar has been laid off, should accompany each party of levellers. The staves should be compared with it at least twice during the course of the season near the origin and terminus of operations. Additional comparisons at intervals of six weeks or two months would also be advisable, especially if the rise or fall is great, and its value is likely to be affected by the slight variations in length to which the staves are liable.

(O.) The staves hitherto made up for our operations are both shod and capped with brass, the extreme graduations being laid off on the brass. This is unfortunate, for the wood of the staves has a tendency to shrink, and a partial separation from the brass has been caused in some instances. Thus a zero error is introduced, which increases the distance between the extremities of the graduation, and must be allowed for in determining the unit of the staff. The amount of separation may be measured, and subtracted from the length between the extreme graduations. A preferable method is, take off a foot exactly with a beam compass from any of the intermediate feet 1 to 9 (all of which are defined by dots on brass pins let into the staff), and mark where one end of the compass falls on the brass, while the other end is on the nearest foot. The mark will indicate the true position of the zero before separation, and if it is referred to when the staff is compared with the portable standard, no subsequent corrections will be needed.

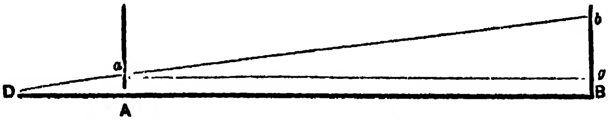
(P.) Notwithstanding that errors of adjustment are cancelled by working with staves at equal distances, an observer should always be careful to keep his instrument in good adjustment. As there will generally be two levels and a theodolite with each party, two of these can be used as collimators, while the third is adjusted between them, according to Gauss' system of collimating, which is explained in detail in the Departmental Instructions. When from want of instruments this method is impracticable, the adjustments may be executed as follows:—

1*st.*—To bring the horizontal wire of the diaphragm into the visual axis of the telescope. Set up an instrument exactly midway between and in the same line with two staves at C between A and B. Find the difference of level between the staves, which can be done,

Fig. 1.

truly at C, notwithstanding errors of adjustment. Then shift the instrument to a point beyond, but within a short distance of one of the staves, as at D, near A, and so place it that both staves may be simultaneously seen in the field of the telescope. Level carefully, and then observe the apparent difference of level between A and B. If the horizontal wire is not in the visual axis of the telescope, the apparent difference of level will differ from the true by an amount $= b\,g$ in *fig.* (2), where D b is the apparent line of sight, and D B the

Fig. 2.



true. The wire must be brought by the diaphragm screws opposite to B, the instrument remaining level. The position of B will be determined by the proportion

$$b\,\mathrm{B} = \frac{b\,g \times \mathrm{D\,B}}{\mathrm{A\,B}}$$

2*nd.*—To make the visual axis of the telescope perpendicular to the axis of motion.

Fig. 3.

Set up the instrument between the staves, but much nearer one than the other, as at E, between A and B. Again observe the apparent difference of level between A and B, which will differ from the true by the amount $b\,h$ (*Fig.* 3) if the visual axis is not at right angles to the axis of motion. The horizontal wire should be made to intersect B, not by the diaphragm screws, but by the adjusting screws under and near each extremity of the horizontal plate. The position of B may be determined from the proportion

$$b\,\mathrm{B} = \frac{\mathrm{E\,B} \times b\,h}{h\,f} = \frac{\mathrm{E\,B} \times b\,h}{\mathrm{E\,B} - \mathrm{A\,E}}$$

This adjustment will of course disturb that of the bubble, which must afterwards be corrected by its own adjusting screws. The whole operation should then be repeated.

(Q.) The new rectangular level has no horizontal plate with adjusting screws. Its visual axis should be set up at right angles to the axis of motion by moving the screws of the diaphragm. With this instrument equal distances between it and the staves are still more necessary than with common instruments, as there is no means of effecting the double adjustment above described. When the focussing tube does not move truly parallel to the visual axis, error would be introduced were the distances unequal.

(R) In adjusting the spirit level to the axis of motion, the observer must recollect that the bubble should be exactly bisected crosswise by the edge of the scale.

(S.) When levelling alternate sections in opposite directions, as suggested in para. K, and the sections are the length of a day's work, the majority of them will necessarily have to close on the temporary wooden pins over which the line is carried, because permanent bench-marks cannot be conveniently laid down oftener than once in 12 miles. Either in commencing or closing a section, the adjoining station of the neighbouring section must be remeasured, as suggested in para. H, to test whether the pins have remained in the position in which they were left. In consequence of alternating the direction of operations the verification is made in the opposite direction to the first measurement, consequently the two results have different signs; they cannot be conveniently combined together, and the mean employed, as when the work is only carried in one direction, and there is a liability to confusion at the time, and subsequent misapprehension if the results are brought up by any one but the leveller himself. This should be carefully guarded against by lucid explanations in the column of remarks, or, better still, by the method of recording the repetition in the Field Book. A clear space of two inches should be left between the record of the extreme station of the section in progress and that of the repeated station of the adjacent section, and the reduction to origin of the section in progress should be entered above the record of the repetition. Opposite the repetition a remark might be made as follows:—

$$\left.\begin{array}{l}\text{By up line fall} \quad \ldots \; 2{\cdot}327 \\ \text{By down line rise} \quad \ldots \; 2{\cdot}331\end{array}\right\}$$

The terminal pins should be large and strong, firmly driven, and covered over with thorns for protection. A trench should be cut across the line at the extremity of each section to guard against the possibility of introducing into one section the stations of another.

(T.) Great care should be taken in reading the indications of the bubble. The instrument generally stands at such a height that it is impossible for the observer to look down on it. From above, the bubble is seen to be sharply defined and the scale can be read with great accuracy; but the observer usually stands with his eye nearly on a level with the instrument, in which position the rim round the bubble, caused by the adhesion of the liquid to the sides of the glass tube, becomes so prominent, that, in certain lights, its extremities may be taken for the true ends of the bubble. When light falls obliquely on the instrument, the outer edge of the rim being towards the light, is more clearly defined than the inner edge, while at the opposite end of the bubble the inner edge, or true end, is most clearly defined. Hence there is a liability to read one end erroneously, and thus introduce one or two divisions of level error. This must be most carefully guarded against, and the observer should take as many opportunities as he can of reading the bubble with his eye above the instrument, and again with his eye on the same level, until he is satisfied that his readings are correct.

The following additional observations on the subject are extracted from a paper communicated by Lieut.-Colonel J. T. Walker to the Royal Astronomical Society, which will be found in Vol. XXXIII of the Memoirs of the Society:—

"It was found that the sun exercises a constant dislevelling effect on instruments, tending to raise the end towards itself and lower the opposite end. This was shown by the excess of negative corrections for level error in lines worked from south to north, and positive corrections in the opposite lines. Thus an error in the adopted value of the run of the level would affect the result by the same fraction of the accumulated corrections, that *it* is of the run. In practice this may be cancelled by watching the signs of the corrections, and occasionally tilting the instrument to counteract the disposition to rise towards the sun. There is yet, however, another order of error, which no *modus operandi* will wholly cancel,* for however carefully the instrument may be shaded, the action of the sun tends to cause a constantly recurring displacement in level, in the interim between the reading of a staff and that of the bubble-ends; these readings should be strictly simultaneous, in order to correspond with each other, but they are necessarily consecutive, and short as the interval between them may be, it is enough to cause slight error, of a cumulative nature, which may amount to a large quantity at the end of a long line of levels. It would be a maximum on a meridional line, but would not affect a line carried from east to west or *vice versa.*

"This error is of a class which cannot be eliminated by working in a circuit; so long as the cause remains constant, the effect is the same in both the up and down operations; thus the opposite points of a circuit, which closes without apparent error, may yet be considerably erroneous.

"In relevelling occasional stations, it was often noticed that different results were obtained at different times of the day, especially when the rays of light grazed the ground in passing from the staff to the observer. Occasional experimental observations were taken throughout a whole day to staves which were very firmly set up for the purpose. A tendency to a diurnal law of variation was found in settled weather, when the sun shone brightly, and the sky was perfectly clear and cloudless, but it was never found when the sky was clouded, however slightly. The results of two series of experiments which were taken on consecutive cloudless days, are herewith given. Three instruments were placed side by side, in the same horizontal plane, on a line facing the south-west. Three staves were set up to the south-west, at distances of 2, 4, and 6 chains, and three others to the north-east, at corresponding distances, forming pairs for observation. The instruments were on a ridge of sand about 1½ feet above the ground level; the lowest staff reading was 4½ feet above the ground, the surface of which had a slope of 1 in 800 upwards from south to north. Each staff was simultaneously observed by three persons, one at each instrument. The differences of the means so obtained for each pair, from the whole of the observations to the pair, are as follows, indicating an increase of variation corresponding to an increase in the distances of the staves:—

* The level reading might be taken before the staff readings at one station, and after them at the next; but this would probably only alter the sign of the error, without diminishing its amount; for there is sometimes much delay over the staff readings, but never over those of the level: hence a longer period would elapse between the respective readings when the level is first read, than when the staff is first read.

From Sunrise to Sunset, 11th January, 1859.								Similarly on 10th January.		From both days combined.	
Staves A, A at 2 Chains.		Staves B, B at 4 Chains.		Staves C, C at 6 Chains.		A + ½ B + ⅓ C = 6 Chains.		A + ½ B + ⅓ C = 6 Chains.			
Times.	Differences from Mean in feet.	Times.	Differences from Mean in feet.	Times.	Differences from Mean in feet.	Times.	Differences from Mean in feet.	Times.	Differences from Mean in feet.	Times.	Differences from Mean in feet.
h. m.		h. m.		h. m.		h. m.		h. m.		h. m.	
7 19 A.M.	+·0009	7 13 A.M.	+·0003	7 1 A.M.	+·0037	7 12 A.M.	+·0023	8 34 A.M.	+·0007	7 12 A.M.	+·0023
7 48 "	+·0014	7 35 "	+·0015	7 29 "	—·0007	7 35 "	+·0019	9 13 "	—·0006	7 35 "	+·0019
8 41 "	—·0012	8 36 "	+·0003	8 30 "	·0000	8 36 "	—·0010	9 53 "	—·0020	8 35 "	—·0002
8 58 "	—·0014	8 53 "	—·0005	8 48 "	—·0057	8 53 "	—·0036	10 14 "	—·0006	9 3 "	—·0022
11 14 "	—·0011	11 10 "	—·0025	11 6 "	—·0013	11 10 "	—·0033	12 19 "	—·0030	10 4 "	—·0013
3 4 P.M.	+·0003	2 57 P.M.	—·0017	2 50 P.M.	—·0027	2 57 P.M.	—·0015	1 49 P.M.	—·0027	11 10 "	—·0033
4 30 "	—·0002	4 25 "	+·0011	4 18 "	—·0010	4 25 "	0000	3 14 "	—·0006	12 19 "	—·0030
5 51 "	+·0011	5 10 "	+·0025	5 13 "	+·0074	5 12 "	+·0048	4 28 "	+·0011	1 49 P.M.	—·0027
								4 45 "	+·0010	3 6 "	—·0011
								5 0 "	—·0062	4 27 "	+·0006
										4 45 "	+·0010
										5 3 "	+·0055

"Atmospheric influences must tend to cancel each other, on a long line of operations, excepting under the following circumstances: *First.*—When more stations are observed before than after noon, they are more liable to a sinking than a rising refraction. Consequently the first of a pair of staff readings will have a tendency to be more refracted than the second, thus introducing cumulative error, unless the precaution is taken to alternate the order of observation, by taking the back staff first at one station and the forward staff first at the next. *Secondly.*—When operations are carried over a line of country which slopes uniformly in one direction, as in proceeding from the sea to the foot of a range of mountains, the rays of light from the up staff to the observer are generally nearer the ground than those from the down staff, and they must, therefore, be more subject to extremes of refraction. In India there are more working hours while the ground is heated by the sun and the refraction is negative, than there are while the refraction is positive. Consequently the rays from the up staff are more lowered by refraction than those from the down staff, or, in other words, there will be a tendency to diminish the amount of the rise from the sea to the hills. The influence of this source of error will vary with the seasons; it is evidently beyond the control of the observer.

"The sinking of a peg that supports a staff, in the interval between its being the forward end of one station and the back end of the next, has often been suggested as a cause of error. But there appears to be at least as much reason for a firmly-driven peg to be raised by the reaction of the ground as to be lowered by the weight of the staff, and there are nearly as many instances in which the signs of the errors indicate the possibility of the one event having happened as the other.

"The maximum difference between the results obtained by two persons working in concert, in the manner already indicated, has been nearly as much as a foot, at the end of a season's work of upwards of 300 miles of levels. The average difference deduced from four sections of a total length of 1,411 miles, is ·15 of a foot per 100 miles.

"A comparison between the results of the spirit levelling operations and those obtained from the principal triangulation is highly satisfactory, in all instances where the vertical angles were measured at the time of minimum refraction, even when the triangulation has been carried for long distances over the extensive plains already noticed. For though at that time the air is not in the state of calm repose which usually prevails toward sunset, but is boiling and seething under the sun's rays, giving signals in the plains an appearance of dancing wildly up and down and gyrating in circles round their centres, the errors of observation which are thus introduced are now found to cancel each other, to a great extent, in a long line of operations. The average amount of error generated on four lines of trigonometrical levels, averaging 550 miles in length, is 3·06 feet, and the maximum error at any station is 8·7 feet, which occurs in the valley of the Indus, at a distance of fully 200 miles from the nearest hill station.

"With regard to spirit levelling, the following inferences may be drawn from the experience which has been gained on these operations. When the precautions which are taken to guard against accidental gross errors, such as misreadings of the feet and tenths, mistaking the identity of the pins on the line, or confounding one bench-mark with another, are such as to preclude the possibility of any error arising from these causes, certain other precautions must still be taken against the accumulation of minute errors, which may arise from instrumental defects from the rising of the pins on hard ground, or their sinking on soft ground, from rising or sinking refraction, from personal bias, from the effect of the sun in disturbing the horizontality of the instrument in the interval between the staff and level readings, from unequal illumination of the ends of the bubble, and from working continuously over a long slope, on which the average height above the surface of the ground will be sensibly different for the up and down rays.

"The alternation of the order of observation of the back and forward staves at consecutive stations, should eliminate all error arising from the three first sources. There is no very obvious reason for also varying the direction of operation in adjacent sections; but after the first alternation has been rigorously carried out, a further reduction of error has been found to attend the adoption of the second, enough to compensate the trouble it necessarily involves in doubling the distance to be travelled; the divergences between the up lines of two observers are generally of an opposite sign to those on the down lines, and, consequently, there is usually less divergence at the advanced end of a pair of up and down sections, than is found to exist in either section singly.

"Errors of other orders which cannot at all be eliminated by methods of alternations may be met to some extent by multiplying the number of observers, in order to diminish the effects of individual bias, and by working under every possible variation of climate. It has been found that, in changeable weather, the discordances between two observers, though, perhaps, greater than in fine weather, cease to be accumulative, and, consequently, cancel each other, while, on the other hand, continuous divergence has most usually been attendant on a long duration of bright sunshine and calm, such as is of frequent occurrence in tropical countries."

On the Determination of the Run of a Level, and the Application of Correction for Dislevelment.

The simplest method of determining the run of a level is to attach the level to the vertical circle of an alt-azimuth instrument, or a theodolite, and taking the readings of the micrometers or verniers of the circle, in two positions of the bubble—the readings of which must also be taken—to compare the number of divisions of the level scale run over by the bubble, with the corresponding angular motion of the vertical circle, as measured by the micrometers or verniers; then the value in seconds of arc of one division of the level scale, or in other words the run of the level, will be obtained by simple proportion. This method is described in Appendix B. to Sir Andrew Waugh's instruction for Topographical Surveying, which will be found at the beginning of this Appendix.

When the run of a level is known, it is easy to ascertain the correction to a staff reading for any amount of dislevelment within the range of the bubble of the level. Thus suppose the value of one division of the scale to be equal to 4 seconds of arc, which is about the average value for ordinary levels having scales with 20 divisions to the inch; the amount subtended by an angular deflection measured by the movement of the bubble through one division of the scale would equal 4 times the amount subtended by an angle of 1 second at the given distance. At a distance of 1,000 feet an angle of 1 second subtends ·00485 feet = (1000 × sin 1″) = (1000 × ·00000485); thus the subtense for 1 division of the scale would be equal to ·019 feet on a staff at that distance; similarly the subtense of an amount of dislevelment indicated by 2 divisions would be ·039 feet, on a staff at the same distance. With such a datum it is necessary to construct a table of subtenses for varying amounts of dislevelment and ranges of distance. As the staves are divided into tenths and hundredths, and the readings should be estimated to thousandths of feet, the subtenses must be expressed in thousandths.

But when there is no alt-azimuth instrument or fairly graduated theodolite available, the run of the level may be determined by directing the levelling instrument on a staff set up at any convenient distance at which it can be read with accuracy, taking a series of staff readings, and comparing their differences with the differences of the corresponding readings of the bubble. The observations should be taken in the morning, before the atmosphere is agitated by the sun's rays, or in the afternoon, a couple of hours before sunset; a cloudy day is preferable to one of bright sunshine for the purpose.

The following is an example of this process, by readings on a staff set up at a distance of 10 chains from the instrument :—

Level Readings.		Differences of Level Readings.			Staff Readings in feet.	Differences of Staff Readings.	Amount subtended by 1 division of Level.
Back end.	Forward end.	Back end.	Forward end.	Mean.			
130·1	68·8				8·613		
68·6	128·9	61·5	60·1	60·80	9·465	·852	·0140
130·1	67·6	61·5	61·3	61·40	8·575	·890	·0145
70·7	126·5	59·4	58·9	59·15	9·413	·838	·0142
129·0	68·4	58·3	58·1	58·20	8·623	·790	·0136
69·7	126·8	59·3	58·4	58·85	9·398	·775	·0132
129·2	67·0	59·5	59·8	59·65	8·608	·790	·0132
67·1	127·4	62·1	60·4	61·25	9·450	·842	·0137
129·8	63·8	62·7	63·6	63·15	8·575	·875	·0139
65·7	127·0	64·1	63·2	63·65	9·463	·888	·0140
131·9	60·7	66·2	66·3	66·25	8·468	·995	·0150
64·3	127·0	67·6	66·3	66·95	9·383	·915	·0137
128·3	62·5	64·0	64·5	64·25	8·550	·833	·0130
65·4	124·4	62·9	61·9	62·40	9·335	·785	·0126
129·9	59·7	64·5	64·7	64·60	8·450	·885	·0137
61·8	126·2	68·1	66·5	67·30	9·355	·905	·0134
129·7	58·6	67·9	67·6	67·75	8·445	·910	·0134
62·3	124·6	67·4	66·0	66·70	9·330	·885	·0138

The general mean of the above determinations is = ·0137. Similar observations were taken at distances of 8 and 5 chains, the former giving a subtense of ·0102, the latter a subtense of ·0069. Combining these together the value to be adopted as the subtense of 1 division, at a distance of 10 chains $= \frac{1}{3}\left\{ \cdot0137 + \frac{10}{8} \times \cdot0102 + \frac{10}{5} \times \cdot0069 \right\}$

$= \cdot0134$ feet.

On this value the following Table of Subtenses has been computed :—

TABLE OF SUBTENSES.

Divisions.	Distances in Chains. 1	2	3	4	5	6	7	8	9	10	Divisions.
0·1	·000	·000	·000	·001	·001	·001	·001	·001	·001	·001	0·1
·2	·000	·001	·001	·001	·001	·002	·002	·002	·002	·003	·2
·3	·000	·001	·001	·002	·002	·002	·003	·003	·004	·004	·3
·4	·001	·001	·002	·002	·003	·003	·004	·004	·005	·005	·4
·5	·001	·001	·002	·003	·003	·004	·005	·005	·006	·007	·5
·6	·001	·002	·002	·003	·004	·005	·006	·006	·007	·008	·6
·7	·001	·002	·003	·004	·005	·006	·007	·008	·008	·009	·7
·8	·001	·002	·003	·004	·005	·006	·008	·009	·010	·011	·8
·9	·001	·002	·004	·005	·006	·007	·008	·010	·011	·012	·9
1·0	·001	·003	·004	·005	·007	·008	·009	·011	·012	·013	1·0
·1	·001	·003	·004	·006	·007	·009	·010	·012	·013	·015	·1
·2	·002	·003	·005	·006	·008	·010	·011	·013	·014	·016	·2
·3	·002	·003	·005	·007	·009	·010	·012	·014	·016	·017	·3
·4	·002	·004	·006	·008	·009	·011	·013	·015	·017	·019	·4
·5	·002	·004	·006	·008	·010	·012	·014	·016	·018	·020	·5
·6	·002	·004	·006	·009	·011	·013	·015	·017	·019	·021	·6
·7	·002	·005	·007	·009	·011	·014	·016	·018	·021	·023	·7
·8	·002	·005	·007	·010	·012	·014	·017	·019	·022	·024	·8
·9	·003	·005	·008	·010	·013	·015	·018	·020	·023	·025	·9
2·0	·003	·005	·008	·011	·013	·016	·019	·021	·024	·027	2·0
·1	·003	006	·008	·011	·014	·017	·020	·023	·025	·028	·1
·2	·003	·006	·009	·012	·015	·018	·021	·024	·027	·029	·2
·3	·003	·006	·009	·012	·015	·018	·022	·025	·028	·031	·3
·4	·003	·006	·010	·013	·016	·019	·023	·026	·029	·032	·4
·5	·003	·007	·010	·013	·017	·020	·023	·027	·030	·034	·5
·6	·003	·007	·010	·014	·017	·021	·024	·028	·031	·035	·6
·7	·004	·007	·011	·014	·018	·022	·025	·029	·033	·036	·7
·8	·004	·008	·011	·015	·019	·023	·026	·030	·034	·038	·8
·9	·004	·008	·012	·016	·019	·023	·027	·031	·035	·039	·9
3·0	·004	·008	·012	·016	·020	·024	·028	·032	·036	·040	3·0
·1	·004	·008	·012	·017	·021	·025	·029	·033	·037	·042	·1
·2	·004	·009	·013	·017	·021	·026	·030	·034	·039	·043	·2
·3	·004	·009	·013	·018	·022	·027	·031	·035	·040	·044	·3
·4	·005	·009	·014	·018	·023	·027	·032	·036	·041	·046	·4
·5	·005	·009	·014	·019	·023	·028	·033	·038	·042	·047	·5
·6	·005	·010	·014	·019	·024	·029	·034	·039	·043	·048	·6
·7	·005	·010	·015	·020	·025	·030	·035	·040	·045	·050	·7
·8	·005	·010	·015	·020	·025	·031	·036	·041	·046	·051	·8
·9	·005	·010	·016	·021	·026	·031	·037	·042	·047	·052	·9
4·0	·005	·011	·016	·021	·027	·032	·038	·043	·048	·054	4·0
·1	·005	·011	·016	·022	·027	·033	·038	·044	·049	·055	·1
·2	·006	·011	·017	·023	·028	·034	·039	·045	·051	·056	·2
·3	·006	·012	·017	·023	·029	·035	·040	·046	·052	·058	·3
·4	·006	·012	·018	·024	·029	·035	·041	·047	·053	·059	·4
·5	·006	·012	·018	·024	·030	·036	·042	·048	·054	·060	·5
·6	·006	·012	·018	·025	·031	·037	·043	·049	·055	·062	·6
·7	·006	·013	·019	·025	·031	·038	·044	·050	·057	·063	·7
·8	·006	·013	·019	·026	·032	·039	·045	·051	·058	·064	·8
·9	·007	·013	·020	·026	·033	·039	·046	·053	·059	·066	·9
5·0	·007	·013	·020	·027	·034	·040	·047	·054	·060	·067	5·0

The dislevelment must be deduced from the readings of the bubble, and may be expressed in terms of the divisions of the scale. As the numbering of the divisions is carried from the centre outwards, the two end readings are identical when the bubble is exactly in the middle of its tube; hence it is evident that if the level were truly adjusted to the visual axis of the telescope, the instrument would be in a truly horizontal position when the readings of the two ends of the bubble are identical, and that when these readings are not identical, half their difference would indicate the amount of the deflection of the instrument from horizontality. As however there is no certainty that the level is in exact adjustment to the visual axis of the telescope, it is necessary, after having taken a pair of readings of the bubble, to turn the instrument through an exact semi-revolution, and take a fresh pair of readings; the four readings must then be combined together in such a manner as to eliminate the effect of the error of adjustment, in deducing the amount of the dislevelment.

Suppose the telescope to have been pointed to the north in the first instance, and let a_n be the corresponding reading of the end of the bubble towards the north, and a_s that of the end towards the south when the instrument was in this position; also let b_n b_s be the readings of the ends of the bubble which were respectively towards the north and south, after the instrument had been moved through a semi-revolution, bringing the telescope to point to the south. Then the true amount of dislevelment, expressed in divisions of scale, will be

$$= \frac{1}{4}\left\{ (a_n + b_n) - (a_s + b_s) \right\}$$

or one-fourth of the difference between the sum of the north end readings, and the sum of the south end readings. If the sum of the readings towards the north is greater than that of the readings towards the south, the north end of the instrument will be above, and consequently the south end below, the horizontal plane passing through the centre of the instrument;—the reverse will be the case when the sum of the south end readings is greatest.

In practice it is not necessary to reverse the instrument and take two pairs of readings for the mere elimination of the error of the adjustment of the level to the visual axis of the telescope, as this purpose is answered by the readings which are taken when the telescope is pointed in succession to the back and forward staves.

At each station the difference of level between the back and forward staves must be approximately deduced in the first instance by subtracting the reading of the forward staff from that of the back staff; the result will be +, indicating a rise, when the back staff reading is greatest, and —, indicating a fall, when the back staff reading is least. This approximate result must now be corrected for the dislevelment of the instrument. The amount and sign of the correction may be conveniently determined by the following rule :—

Consider the back end level readings to be —, and the forward end to be +. Find their difference, and enter it with the sign of whichever is greatest. Half the algebraical sum of the differences is the quantity for which a correction is to be taken from the subtense table. The correction to have the same sign as the half sum, and to be applied algebraically to the approximate rise or fall deduced from the staff readings.

This rule follows from the formula above given, on writing it in the form

$$\frac{1}{4}\left\{ (a_n - a_s) + (b_n - b_s) \right\}$$

which deals with the sum of small differences, instead of the difference of large sums, and is therefore practically less troublesome. One-fourth the algebraical sum indicates the instrumental dislevelment, the effect of which on the approximately deduced rise or fall will evidently be equal to the sum of the subtenses on the back and forward staff, or twice

the value given by the subtense table. Hence the direction is the rule to take one-half instead of one-fourth of the algebraical sum.

To facilitate the determination of the signs of the corrections for dislevelment, the bubble readings are entered in the Field Books of the Trigonometrical Survey in two columns, one headed Back End, the other Forward End; strictly speaking, however, this nomenclature is correct only when the instrument is in the line between the staves, for then if one end of the level is towards the back staff or forward staff, the other end must be towards the opposite staff. But when the instrument is on either side of the line between the staves, one end of the level is towards the staff on which the telescope is pointed, and the other is towards the opposite direction, not towards the other staff. In the first instance twice the absolute amount of the instrumental deviation from horizontality is determined by the preceding method; in the second, twice the difference between the respective amounts of dislevelment in the two vertical planes passing through the instrument and the staves is determined, and this is all that is required for the correction of the observations, provided that the essential condition of setting up the instrument at equal distances from the staves has been fulfilled.

Practical illustrations of the method of applying the corrections for dislevelment will be found in the accompanying specimen of the Field Book used in the levelling operations of the Trigonometrical Survey; the treatment of stations 2, 3, 4, and 5 of the levels between Jorah village and Deori village may be specially referred to as exemplifying all cases likely to occur in practice.

The 1st column of the Field Book gives the number of the station and indicates the horizontal lines on which the observations to the respective staves are entered; six of these lines are required at each station, three for the observations to the black faces and their reduction, and three for the white faces. The 2nd column gives the distances and bearings of the staves from the instrument, which are necessary to enable the line of levels to be protracted. The 3rd and 4th columns give the back and forward end readings of the bubble, the 5th and 6th the calculations of dislevelment, and the 7th the corresponding correction obtained from the Subtense Table expressed in thousandths of a foot, omitting decimal points and cyphers. The 8th column gives the staff readings; the 9th and 10th the approximate results deduced by subtracting the reading of the forward from that of the back staff, one column being allotted to rises, the other to falls. The 11th and 12th columns give the true differences of level, *i.e.*, the approximate values of the 9th and 10th columns corrected for dislevelment; in these columns the mean of the results from black and white faces is also entered. The 13th column gives the reduction of the levels to the origin of the line, which should be deduced station by station, and checked by summing up the rises and falls at the foot of the page, as indicated. The 14th column is reserved for remarks and descriptions of the bench-marks;—it is of course obvious that the latter should be sufficiently lucid to enable any person who may have occasion to visit a bench-mark, either for the purpose of commencing or closing a new line of levels, to ascertain the exact position of the mark without the slightest doubt; drawings of the bench-marks should always be given, with their distances and bearings from any prominent buildings in the neighbourhood. The remaining columns on the right hand side are required for the entry of details regarding the small cumulative errors which are described in the first pages of this Memoranda.

In the operations of the Trigonometrical Survey the level and staff readings are recorded for the observer by a native assistant, who calculates the results, before handing the Field Book over to the observer, by whom they are checked before the instrument is removed to the next station. Any native who knows how to add and subtract, and can write English numerals, will suffice for the purpose of recording the observations. The headings, remarks, and descriptions of stations should invariably be written by the observer.

LATITUDES AND LONGITUDES OF PLACES OF NOTE.

Derived from the Records of the Great Trigonometrical Survey and other reliable geographical sources.

ASSAM.

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Cachar ...	Asaloo Mark ...	25 11 26	93 13 10	2,683	Note.—All the Longitudes are referrible primarily to the old value of the Madras Observatory, 80° 17′ 21″, to which a correction of —3′ 1″·5 is required to reduce to the results of Captain Jacob's determination.
	Cachar Church* ...	24 49 42	92 50 48		
	Hailakandi Centre of Village ...	24 40 3	92 39 55		
	Katigora Centre of Village ...	24 52 56	92 37 30		
	Lakhipur ditto ...	24 47 30	93 2 42		
Durrung ...	Bisnath Centre of Village ...	26 40 10	93 12 40		
	Mangaldai Centre of Village ...	26 27 30	92 4 35		
	Tezpur Church* ...	26 37 8	92 50 22	303	
	Odalguri Thannah ...	26 45 36	92 9 29		
Garo Hills	Dalu Centre of Village	25 13 8	90 15 38		
	Damalgiri Centre of Village ...	25 31 50	90 9 35		
	Tura Dy. Commr.'s Bungalow ...	25 30 50	90 15 45	1,323	
Goalpara...	Doobri Rock Over Town* ...	26 1 5	90 2 17	158	
	Goalpara Hill Over City* ...	26 10 53	90 40 32	399	
Kamroop ...	Burpeta Centre of Village ...	26 19 45	91 3 20		
	Diwangiri ditto ...	26 53 20	91 30 50		
	Gowhatty Church* ...	26 11 18	91 47 26		
Khasia and Jyntia Hills ...	Cherra Poonjee Church Steeple* ...	25 15 58	91 46 42		
	Jowye Mission House	25 26 14	92 14 28		
	Shillong Court House	25 34 18	91 55 43	4,951	
	Kollong Rock* ...	25 36 13	91 36 2	5,814	
Lakhimpur..	Debrooghur City Centre ...	27 28 30	94 57 30		
	Jaipur Centre of Village ...	27 15 0	95 26 0		
	Lakhimpur City Centre ...	27 14 0	94 9 21		
	Sadiya Centre of Town ...	27 48 55	95 41 55		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

ASSAM.—(*Continued.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Naga Hills	Dimapur Fort ...	25 54 30	93 47 5		
	Japvo Hill Survey Sn.	25 35 53	94 5 41	9,890	
	Kadiuba Hill Survey Station ...	25 46 51	23 59 12	4,576	
	Nidzukru Hill Survey Station ...	25 51 8	94 12 25	5,742	
	Simagooting Centre of Station ...	25 46 50	93 49 40	2,477	
Nowgong ...	Dabuka Centre of Village ...	26 7 0	92 55 0		
	Nowgong Jail* ...	26 20 33	92 43 31	218	
Sibsagar ...	Golaghat Centre of Village ...	26 30 25	94 0 0		
	Jorehaut Centre of Village ...	26 45 30	94 15 58		
	Sibsagar Great Temple* ...	26 59 19	94 40 37	460	
Sylhet ...	Abidabad Centre of Village ...	24 33 15	91 16 36		
	Chattack Monument*	25 2 10	91 42 20		
	Jaintiapur Thannah*	25 8 7	92 10 2		
	Sylhet Church* ...	24 53 23	91 54 40		

BENGAL, LOWER PROVINCES.

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Backergunj	BackergunjCityCentre	22 32 30	90 22 25		
	Burrisal Centre of Village ...	20 41 50	90 24 20		
	Pirijpur Centre of Village ...	22 34 30	90 0 40		
Balasore ...	Balasore Spire* ...	21 30 12	86 58 16		
	Bhadruk Centre of Town ...	21 3 0	86 33 31		
	Jellasore ditto ...	21 47 30	87 13 26		
Bankura ...	Bankura Telegraph*	23 14 8	87 6 31		
	Bishenpore Dome* ...	23 4 21	87 22 11		
	Raghonathpore Tel.*	23 31 31	86 42 32		
Bhagulpore ...	Bhagulpore Cleveland Monument* ...	25 15 16	87 2 29		
	ColgongVillageCentre	25 15 15	87 16 51		
	Nathpur ditto ...	26 19 40	87 7 41		
	Permesaipur ditto ...	25 23 30	86 58 36		
	Sultanganj ditto ...	25 14 45	86 47 6		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

BENGAL, LOWER PROVINCES.—(*Continued.*)

District.	Place.	Latitude. ° ′ ″	Longitude. ° ′ ″	Height above Sea. Feet.	Remarks.
Beerbhoom	Illambazar Town Centre ...	23 37 30	87 34 41		
	Khirnee Town Centre	23 51 55	87 19 51		
	Moliser ditto	23 59 5	87 48 31		
	Soori Jail*	23 54 23	87 31 14		
Bogra ...	Adhumdighi Centre of Village ...	24 49 5	89 5 15		
	Bogra City Centre ...	24 50 40	89 25 41		
	Budalgachi Centre of Village ...	24 59 50	88 57 11		
	Sibganj ditto ...	25 1 0	89 22 6		
Burdwan ...	Assensole Village Centre ...	23 41 45	87 0 51		
	Burdwan Centre of Town ...	23 15 50	87 53 41		
	Culna Temple* ...	23 13 20	88 24 31		
	Raniganj Centre of Town ...	23 36 30	87 8 20		
Champaran	BettiahRaja'sPalace*	26 48 5	84 32 40	247	B. M. in Raja's House.
	Moteeharee Village*	26 39 46	84 57 29	216	B. M. in Collector's Katchori.
	MullyeBurialGround*	26 5 27	85 29 12		
	Segowlie Temple* ...	26 46 41	84 47 51	224	B. M. in Temple near Maharaj Rajendar Kisore Sing's well.
	Ramnagar Raja's House* ...	27 9 53	84 22 2		
	Ratwal Town House*	27 0 58	84 14 1		
Chittagong	Barkul Falls ...	22 44 59	92 24 28	1,830	
	Bunderbain Village Centre ...	22 12 0	92 16 10		
	Chittagong Judge's Court* ...	22 21 3	91 52 44		
	Cox's Bazar Mug temple near Court House* ...	21 26 31	92 1 2		
	Kumaria Centre of Village ...	22 30 15	91 45 40		
	Mir ka Sarai Centre of Village ...	22 46 4	91 37 10		
	PolataiGuardofTown	22 4 15	92 33 35	2,724	
	Ramu Centre of Town	21 24 55	92 8 40		
	Rangamatia ...	22 38 27	92 14 48	142	
Cuttack ...	Cuttack Fort* ...	20 29 4	85 54 29	132	
	Cuttack Commissioner's House, Lalbaugh* ...	20 27 35	85 53 51		
	Jajipur Village Centre	20 50 45	86 22 56		
	Pattamundi ditto ...	20 35 5	86 36 1		
	Sokinda ditto ...	20 58 40	85 57 1		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

BENGAL, LOWER PROVINCES.—(*Continued.*)

DISTRICT.	PLACE.	Latitude.	Longitude.	Height above Sea.	REMARKS.
		° ′ ″	° ′ ″	Feet.	
DACCA ...	Bhowal Village Centre	23 59 30	90 28 10		
	Bikrampur Fort ...	23 27 5	90 33 20		
	Dacca City Centre ...	23 42 30	90 26 0		
	Manikganj Village Centre ...	23 52 35	90 4 6		
	Sabar Village Centre	23 50 50	90 17 16		
DARJEELING	Birch Hill Survey Station* ...	27 3 23	88 17 53	6,885	
	Daling Fort ...	27 1 8	88 45 0	3,565	
	Darjeeling Church*...	27 2 48	88 18 36		
	Dumsong Centre of Village ...	27 8 13	88 38 8	6,312	
	Hope Town Centre of Village ...	26 56 40	88 17 40		
	Jalapahar Survey Station* ...	27 2 3	88 18 26	7,460	
	Karsion Centre of Village ...	26 52 40	88 19 30	4,520	
	Pankabaree Centre of Village ...	26 50 45	88 18 35	1,800	
	Senchal Hill Survey Station* ...	26 59 5	88 20 11	8,610	
	Tongloo Centre of Village ...	27 1 51	88 7 29	10,084	
DINAJPOOR..	Birganj Village Centre	25 51 30	88 41 40		
	Chintaman ditto ...	25 26 10	88 57 30		
	Dinajpoor, house in Station* ...	25 36 34	88 40 12		
	Nawabganj Village Centre ...	25 25 30	89 7 10		
DURBHANGA	Durbhanga* ...	26 10 2	85 56 39	162	B.M. in Billiard and bath room.
	Mudhubani Centre of Town ...	26 21 10	86 7 9		
	Tajpur Centre of Town	25 51 33	85 48 11		
FUREED-POOR ...	Fureedpore Court-house* ...	23 36 25	89 53 11		
	Pangsa Village Centre	23 47 40	89 26 31		
	Shodpur or Sindpur Village Centre ...	23 25 35	89 42 51		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

BENGAL, LOWER PROVINCES.—(*Continued.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Gurjat States in Chota Nagpore Division. — Bonai...	Bonaigarh Centre of Town ...	21 44 0	84 59 55		
Chang Bhukar.	Janakpura Centre of Town ...	23 42 58	81 50 8		
Gang-pur.	HingirCentreofTown	21 56 30	83 44 23		
	Sundi ditto ...	22 7 30	84 4 30		
Jashpur	Jashpurnagar Centre of Town ...	22 53 0	84 11 10		
Koria...	Sonahut Centre of Town ...	23 29 0	83 33 30		
Sirgu-jah.	Bisrampur ...	23 7 13	83 14 10		
	Jhilmili Town ...	23 24 15	83 53 30		
	Pertabpur ditto ...	23 29 23	83 16 8		
	Ramkola ditto ...	23 39 40	83 1 45		
Udey-pur.	Rabkob Centre of Town ...	22 28 20	83 15 20		
Gya ...	Bajidpur Telegraph*	24 43 28	84 29 58		
	Behar, City, Temple*	25 11 58	85 34 10		
	Budh Gya Pagoda*...	24 41 45	85 2 4		
	Gya,RamsilaPagoda*	24 48 44	85 3 16		
	Hosainabad Town* ...	24 31 31	84 2 6		
	Sherghatty Fort* ...	24 33 24	84 50 28		
	Daodnagar Town* ...	25 2 39	84 26 35		
Hazareebagh ...	Hazaribagh Mausoleum* ...	24 0 1	85 24 8		
	Hazaribagh Church*	23 59 21	85 24 32		
	Khararbari Coal Mines, Bungalow*	24 10 39	86 17 56		
	Parasnath Hill Survey Station* ...	23 57 35	86 10 30	4,480	
	Ramgarh Fort* ...	23 38 22	85 34 5		
Hill Tippera ...	AgartollaRaja'sPalace*	23 50 15	91 19 30		
Hooghly with Howrah	Bandel Church Steeple* ...	22 55 9	88 26 19		
	Chinsurah College*...	22 53 1	88 26 40		
	Serampore Church*...	22 45 26	88 23 10		
	Pondua Durga* ...	23 4 28	88 19 43		
	Hooghly Katcheri Ghat* ...	22 54 44	88 26 28		
	Bali Sugar Work's Chimney* ...	22 38 43	88 23 43		
	FortGlosterChimney*	22 29 26	88 12 59		
	Howrah Rustomjee's House* ...	22 35 16	88 23 12		

¹ Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

BENGAL, LOWER PROVINCES.—(*Continued.*)

District.	Place.	Latitude. ° ′ ″	Longitude. ° ′ ″	Height above Sea. Feet.	Remarks.
Julpaigori	Julpaigori Raja's Palace* ...	26 32 20	88 45 38		
	Siliguri Centre of Village ...	26 41 43	88 27 10		
Kooch Behar ...	Kooch Behar* ...	26 19 36	89 28 53		
	Mainagoreo Temple*	26 17 29	89 24 23		
	Mekuganj Centre of Village ...	26 20 33	88 51 10		
Lohardugga ...	Dorandah Church* ...	23 21 21	85 22 5	2,166	
	Lohardugga House*	23 25 48	84 43 16	2,173	
	Ranchi Court-house*	23 22 37	85 22 6	2,126	
Malda ...	Gajol Village Centre	25 13 8	88 14 20		
	Kaliachak ditto ...	24 51 15	88 3 1		
	Malda City Centre ...	25 2 30	89 11 1		
	Nawabganj Village Centre ...	24 35 48	88 19 1		
Manbhoom..	Chasnunda Village Centre ...	23 38 0	86 13 20		
	Manbazar Village Centre ...	23 3 40	86 42 10		
	Puralia City Centre...	23 19 45	86 24 45		
	Topchanchi Village Centre ...	23 53 55	86 14 40		
Midnapore	Contai Village Centre	21 47 0	87 47 26		
	Danton ditto ...	25 56 55	87 19 21		
	Gurhbeta ditto ...	22 52 20	87 24 0		
	MidnaporeParkhouse*	22 24 48	87 21 12		
	Tumlook Salt Agent's House* ...	22 18 2	87 58 9		
Monghyr ...	Jargaon House* ...	25 27 26	86 43 38		
	Kharakpoor Fort* ...	25 7 21	86 35 52		
	Monghyr Fort* ...	25 22 32	86 [illegible] 21		
	Sultanganj House*...	25 15 14	86 46 49		
Moorshedabad ...	Bhagwangola Centre of Village ...	24 20 0	82 20 38		
	BerhamporeHospital*	24 6 8	88 17 33		
	Moorshedabad Centre of City ...	24 11 5	88 18 50		
	Nalhati Centre of Village ...	24 17 50	87 51 11		
	Sute ditto ...	24 35 20	88 6 8		
Mozufferpur.	Hajipoor Temple* ...	25 40 50	85 11 24		
	HariarChatarTemple*	25 40 49	85 13 50		
	Mozufferpore ...	26 7 23	85 26 52	177	B. M. in Collector's Katcheri.
	Setamuree Centre of Town ...	26 35 20	85 31 33		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

BENGAL, LOWER PROVINCES.—(*Continued.*)

District.		Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
			° ′ ″	° ′ ″	Feet.	
Mymensing		Jamalpur Town* ...	24 56 15	89 58 55		
		Mymensing City* ...	24 45 50	90 26 54		
Noacolly ...		Begamganj Centre of Village ...	22 56 0	91 9 0		
		BulloahVillageCentre	22 52 40	90 56 10		
		Noacolly Town Centre	22 48 0	91 8 0		
		Sundeep Island* ...	22 27 6	91 33 37		
Nuddea ...		Kishnagar City* ...	23 23 23	88 32 37		
		Santipur Temple* ...	23 14 24	88 29 6		
		SooksagorPakaHouse*	23 3 26	88 31 32		
Orissa Tributary States.—Orissa Division.	Angul...	Angul Centre of Town	20 47 50	85 1 26		
	Athgarh	Athgarh ditto ...	20 31 30	85 40 31		
	Athmalik ...	Hondapa ditto ...	20 56 40	84 43 41		
	Banki...	Bankigarh ditto ...	20 21 30	85 33 11		
	Baramba ...	Baramba ditto ...	20 25 15	85 22 41		
	Boad ...	Boâd ditto ...	20 50 20	84 21 41		
	Daspala	Daspala ditto ...	20 18 40	84 56 21		
	Denkanal ...	Denkanal ditto ...	20 39 45	85 38 16		
	Hindol	Hindol ditto ...	20 36 20	85 14 26		
	Keonjhur...	Keonjhur ditto ...	21 37 25	85 37 31		
	Khandcpara...	Khandpara ditto ...	20 15 50	85 12 51		
	Lahara	Lahara ditto ...	21 26 0	85 13 46		
	Mohrbhanj...	Baripada ditto ...	21 56 5	86 45 41		
		Daspur ditto ...	21 57 40	86 7 11		
	Narsinghpur...	Narsinghpurditto ...	20 28 0	85 7 1		
	Nilgiri	Nilgiri ditto ...	21 27 20	86 48 41		
	Nyagarh...	Nyagarh ditto ...	20 7 45	85 7 56		
	Ranpur	Ranpur ditto ...	20 8 55	85 23 26		
	Talchir	Talchir ditto ...	20 57 20	85 16 11		
	Tigaria	Tigaria ditto ...	20 28 15	84 33 31		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

BENGAL, LOWER PROVINCES.—(*Continued.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Patna ...	Dinapore Flag Staff*	25 38 19	85 5 8	171	G. T. S. B. M.
	Patna Gola* ...	25 37 12	85 10 57	172	Lower Step, Top.
	Patna Collectorate Centre Chimney*...	25 37 15	85 12 31		
Pooree ...	Juggurnath Great Temple* ...	19 48 17	85 51 39		
	Khoorda Village Centre ...	20 11 0	86 40 21		
	Pipli Village Centre	20 7 30	85 53 6		
Pubna ...	Chatmohar Village Centre ...	24 13 40	89 20 20		
	Doolai Village Centre	11 57 20	89 34 3		
	Pubna City Centre...	24 0 28	89 17 31		
Purneah ...	Kissenganj Katcheri*	26 7 26	87 58 14		
	Purneah Collectorate*	25 46 15	87 30 44		
	Sonakhoda Base E. Tower* ...	26 18 59	88 19 56	244	
	Sonakhoda Base W. Tower* ...	26 15 25	88 14 30	220	
Rajshahye	Nattore Village Centre	24 25 15	89 2 21		
	Rampore Beauleah, Judge's Courthouse*	24 21 46	88 37 46		
	Tannore Village Centre	24 36 0	88 37 10		
Rungpore...	Bhowaniganj Village Centre ...	25 16 30	89 41 50		
	Chilmari Village Centre ...	25 27 20	89 48 50		
	Nageswari Village Centre ...	25 58 15	89 44 44		
	Rungpore City Centre	25 44 51	89 17 31		
Saran ...	Chapra Collectorate*	25 46 42	84 46 [illegible]9		
	Daraoli Temple* ...	26 4 26	84 10 16		
	Hathwa Raja's Palace*	26 21 36	84 20 21		
	Revelganj Raja's House* ...	25 46 56	84 41 7		
Shahabad...	Arrah Collectorate*	25 33 46	84 42 22		
	" Batson's House*	25 32 3	84 42 18		
	Buxar Fort Flag Staff (old)* ...	25 34 24	84 0 46		
	Domraon Temple* ...	25 32 59	84 11 42		
	Rhotasgurh Building*	24 37 9	83 57 30		
	Sasseram Tomb* ...	24 56 59	84 3 7		
Singhbhoom	Chaibassa City Centre	22 33 15	85 51 0		
	Lalgarh Village Centre	22 14 0	85 54 15		
	Seraikela ditto ...	24 42 25	85 58 40		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

BENGAL, LOWER PROVINCES.—(*Concluded.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Sonthal Pergunnas	Deogurh Temple* ...	24 29 34	86 44 35		
	Jumturrah Centre of Village ...	23 58 10	86 50 51		
	Muddapur ditto ...	24 15 55	86 41 36		
	Nya Doomka Centre of Village ...	24 16 0	87 17 21		
Tipperah ...	Comillah Survey Station* ...	23 27 55	91 13 18		
	Daodcandy Centre of Village ...	23 32 20	90 45 20		
	Hajeeganj Centre of Village ...	23 15 0	90 53 40		
	Jaffirganj Centre of Village ...	23 34 30	91 5 25		
Twenty-four Pergunnas or Presidency.	Akra Semaphore* ...	22 30 26	88 17 36		
	Barrackpore Flag Staff* ...	22 45 40	88 23 52		
	Baraset Magistrate's Katcheri* ...	22 43 24	88 31 45		
	Base Line N. end Tower*	22 42 35	88 25 4		
	Base Line S. end Tower*	22 36 59	88 25 22		
	Calcutta.				
	Armenian Church*	22 34 47	88 23 41		
	Fort Wm. Semaphore Tower*...	22 33 25	88 22 41		
	G. P. O. Dome* ...	22 34 19	88 23 28		
	Govt. House Dome*	22 34 2	88 23 59		
	Kidderpore Church*	22 32 25	88 22 18		
	La Martiniere Dome*	22 32 32	88 24 0	......	Survey Station.
	Ochterlony Monument* ...	22 33 47	88 23 30		
	St. Paul's Cathedral*	22 32 40	88 23 24		
	Surveyor-General's Office, 46 Park Street* ...	22 33 1	88 23 59	18·11	Height of Standard Barometer in Observatory.
	Diamond Harbour Flag Staff* ...	22 11 10	88 13 37		
	Do. do. Semaphore*	22 11 11	88 13 47	......	Custom House.
	Dum-Dum. Church*	22 37 52	88 27 51		
	Hooghly Point* ...	22 12 39	88 7 5		
	Kedgree Semaphore*	21 52 35	88 0 46		
	Kowcolly Lighthouse*	21 50 18	87 59 11		
	Sagar Mud Point Mark* ...	21 55 50	88 9 15		
	Silver Tree Obelisk*	21 57 58	88 11 23		
Soonderbunds ...	Saugor Island Lighthouse* ...	21 38 43	88 5 2		

Ranpur

Talchir Tigaria Tig.

LATITUDES AND LONGITUDES.—(*Continued.*)

BOMBAY PRESIDENCY.

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Ahmedabad	Ahmedabad City Tower clerk* ...	23 1 26	72 37 21		
	Perrim Lighthouse*	21 35 54	72 28 38		
Ahmednagar.	Ahmednagar City Centre ...	19 5 55	74 46 57		
Baroda (Guikwor) Native State.	Baroda clock tower*...	22 17 59	73 15 8	185	
Broach ...	Broach or Baroch Stn.*	21 41 27	73 1 14	140	
Belgaum ...	Belgaum Fort* ...	15 51 37	74 33 59	2,568	
Cutch ...	Bhooj Town Temple*	23 14 52	69 42 21		
	Jekow Bunder* ...	23 13 53	68 43 45		
	Luckpat Sur. Stn. Chaoki* ...	23 49 20	68 49 23	126	
	Mandavi Lighthouse*	22 49 41	69 23 21		
	Veriavow Town* ...	23 30 56	70 48 12		
Darwar ...	Dharwar Katcheri*...	15 27 3	75 2 42	2,586	
Dharwar Principality.	Hebli Hill Edga* ...	15 28 50	75 10 26		
	Nargund H. Temple*	15 43 22	75 25 30		
	Sampgaon Mosque*...	15 47 35	74 47 58		
Kaira ...	Cambay City Bungalow* ...	22 18 40	72 39 25	101	
	Kaira Church* ...	22 44 23	72 45 17		
Kaladghi...	Kaladghi Town Centre	16 12 37	75 52 30		
Katiawar (Native State).	Beyt (Sur. Sta.) Town*	22 27 4	69 8 11		
	Bhownagar Survey Station in Town*...	21 45 55	72 11 14	169	
	Diu Watch Tower (Portuguese Fort)*	20 42 40	71 1 39		
	Dwarka Temple Spire*	22 14 13	69 0 31		
	Gogo House* ...	21 40 43	72 19 30		
	Harsole Residency Bungalow* ...	23 22 18	73 4 39		
	Morvi Palm Tree* ...	22 49 43	70 53 46		
	Navibunder S. E., Temple* ...	21 26 57	69 49 40		
	Palitana* ...	21 29 1	71 50 13		
	Porebunder Fl. Staff*	21 38 17	69 38 13		
	Rajkote Church Tower*	22 18 41	70 50 11		
	Scrow Fort W. Temple*	22 47 36	71 14 41		
Khandesh ..	Arawad Town Centre	22 13 15	75 29 7	656	
	Dhoolia City Centre	20 57 30	74 47 0		
	Saoda Town Centre...	21 8 57	75 55 46	766	
	Pal ditto ...	21 21 30	75 56 27	1,310	
	Ravere ditto ...	21 14 50	76 4 27		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

BOMBAY PRESIDENCY.—(*Continued.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Kolaba ...	Alibagh Town Centre	18 38 38	72 54 56		
Kolapoor ...	Kolapoor Town Centre	16 41 42	74 16 6		
	Panala do. ...	16 54 40	74 53 13		
Konkan ...	Shiu Fort Fl. Staff*	19 2 43	72 54 32		
Nasik ...	Deolali R. Station ...	19 56 30	73 52 1		
	Egutpoora R. do. ...	19 39 40	73 37 26		
	Maligaum H. Pagoda*	19 59 8	75 58 6		
	Nassik, Centre of City	19 59 44	73 49 48		
N. Kanara	GairsappaTownCentre	14 13 10	73 42 48		
	Shadashegurh Flag Staff.* ...	14 50 45	74 10 21		
Pahlampoor Native State.	Deesa Bungalow used as a Church* ...	24 15 44	72 13 55		
	Pahlampoor Temple Dome* ...	24 9 58	72 29 9		
Poonah ...	Bholeshwar H. Pagoda* ...	18 26 5	74 16 58		
	Ganesh Khind* ...	18 32 24	73 52 14		
	Indapoor* ...	18 5 51	75 0 50	1840	
	Khandalla R. Station	18 45 0	73 24 41		
	Kirkee Church* ...	18 33 20	73 53 36		
	Lanowlie R. Station...	18 44 28	73 27 16		
	Patas Pagoda* ...	18 25 55	74 32 25		
	Poona, St. Mary's Church* ...	18 30 28	73 55 33		
	PoorundarH.Pagoda*	18 16 33	74 0 45		
	Singhar Fort* ...	18 21 52	73 47 46		
Portuguese Territory.	Agoada Lighthouse*	15 29 26	73 48 57		
	Anjadeepa Fl. Staff*	14 45 36	74 9 8		
	Cabo Convent* ...	15 27 41	73 49 48		
	Cape Ramas* ...	15 5 12	73 57 27		
	Diu Island Watch Tower* ...	20 42 40	71 1 59		
	Goa Rachol College...	15 18 34	74 2 31		
	Goa St. Dennis' Church or Remaidia*	15 21 24	73 56 30		
	Marmagaom House*	15 16 24	74 0 10		
Ruttnagehri.	DapooleeTownCentre	17 46 35	73 14 36		
	Fort Victoria* ...	17 58 19	73 5 1		
	Makrangarh Fort* ...	17 50 53	73 38 47		
	Ratnagherry Fort* ...	16 59 42	73 18 43		
	Sidéshwar Fort* ...	16 7 57	73 55 15		
	Vingorla Signal* ...	15 51 14	73 39 24		

* Obtained from Great Trigonometrical Survey Records.

N Gari. Ranpur Talchir Ta Tigaria Tiga.

LATITUDES AND LONGITUDES.—(*Continued.*)

BOMBAY PRESIDENCY.—(*Concluded.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Satara ...	Kaota Town* ...	16 58 59	74 39 55		
	Mahableshwar Survey Station* ...	17 55 14	73 42 44	4717	
	Satara City Centre ...	17 41 30	74 2 1		
	Tasgaon Town* ...	17 1 59	74 38 40		
Sawant Wari.	Wari Town Centre ...	15 54 28	73 51 30		
Sholapoor	Kem Survey Station..	18 10 47	75 20 51	2039	
	Sholapoor Fort* ...	17 40 18	75 56 38	1669	
Southern Mahratta Country.	JamkundiCentreTown	16 30 35	75 20 9		
	Kaowta* ...	16 58 59	74 39 55		
Surat ...	Surat MinaretAdrusah*	21 12 19	72 51 57	160	
Tanna ...	Bascin, Centre of Town ...	19 20 10	72 51 14		
	Bombay—				
	Butcher's Island Tower* ...	18 57 31	72 56 41		
	Byculla Church* ...	18 58 5	72 52 23		
	Lighthouse* ...	18 53 40	72 51 10		
	Observatory* ...	18 53 45	72 51 14	114	Height of Road Station near Observatory.
	St. Thomas' Cathl.*	18 55 50	72 52 30		
	Raigarh Palace* ...	18 13 59	73 29 8		
	Tanna, Centre of Town ...	19 11 25	73 1 28		

PROVINCE OF SIND.

Under the Governor of Bombay.

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Hydrabad...	Kotree Fort ...	25 21 41	68 21 37		
	Hydrabad ...	25 23 5	68 24 51	66	Mooring gun.
	Mahomed Khan's Tanda ...	25 7 34	68 34 24		
Kurrachee	Base Line N. End Tower* ...	24 58 44	67 11 52	223	
	Base Line S. End Tower* ...	24 52 59	67 11 52	69	
	Jerruk Hill* ...	25 3 6	68 17 44	84	(Sp. L.) B. M. Dharamsala.
	Kurrachee Observatory* ...	24 49 49	67 4 3	35	

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

PROVINCE OF SIND.—(*Concluded.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Kurrachee.—*Continued.*	Kurrachee Church*...	24 51 9	67 4 15	28	
	Manora Lighthouse...	24 47 21	67 1 17	9	(Sp. L.) B. M.
	Monze Cape* ...	24 50 3	66 42 28		
	MuggerPirSurv.Stn.*	24 59 16	67 3 56	583	
	Tatta Dome* ...	24 44 7	67 57 55	39	(Sp. L.) B. M. in D. B.
Shikarpore	Larkhana House* ...	27 33 26	68 15 32		
	Rati Dehra do.* ...	27 48 10	68 19 47		
	Rohree House* ...	27 41 21	68 55 52		
	Shikarpore House*...	27 57 13	68 40 26	194	(Sp. L.)
	Sukkur House* ...	27 41 40	68 54 27		
Thurr and Paukur Political Agency.	Nyakote Sur. Stn.*...	24 50 39	69 29 28		
	Nubeesur do. *...	25 4 28	69 41 51		
	Oomarkote Fort* ...	25 21 48	69 46 30		
	Wanga Bazar Suvey Station* ...	24 37 12	69 17 2		

BRITISH BURMAH.

Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
	° ′ ″	° ′ ″	Feet.	
Akyab Survey Station, on OldTemple*	20 8 53	92 55 10	72	
Akyab Point, Flag Staff* ...	20 6 45	92 56 30		
Kutubdia Lighthouse* ...	21 52 30	91 53 0	126	
Kyouk-Phyoo western-most Bungalow*	19 26 2	93 34 39		
Myannong Survey Station in Hospital Compound* ...	18 17 53	95 21 32		
Nanthakun or Foul Island Central Hill*	18 3 51	94 8 9		
Nuguan Island Tree* ...	18 26 7	93 57 3		
Port Blair, Chatham Island (Andamans) ...	11 41 13	92 42 44	...	By Astrl. Obsns.
Prome Pagoda on Hill near Palm Tree*	18 47 53	95 18 23		
Sandoway, Nando Temple* ...	18 28 9	94 24 21		
Savage Island, Lighthouse* ...	20 5 7	92 56 39	116	

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

CENTRAL INDIA AGENCY.

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Adjaigarh	Adjaigarh Survey Station ...	24 53 8	80 12 46	1,474	
Bandlecund	Bijaor Centre of Town	24 37 46	79 32 6		
Barwani ...	Barwani Fort ...	22 2 45	74 57 23	651	
	Rajpoor Fort ...	21 56 23	75 10 44	705	
Bhopal ...	Bhelsa Temple ...	23 31 35	77 50 39		
	Bhopal Palace ...	23 15 35	77 25 56		
	Raisen Fort ...	23 19 36	77 49 13		
	Sehore Agency ...	23 11 55	77 7 14		
Bodwar ...	Erinpoorah Cantonment Hospital* ...	25 8 26	73 6 21		
Central India Agency	Manpoor D. B. ...	22 25 32	75 39 19	1,844	
	Mhow Church* ...	22 33 36	75 48 9		
Chatterpoor ...	Chatterpoor Centre of Town ...	24 54 35	79 37 53		
Dattia ...	Dattia Indargarh ...	25 40 13	78 29 35		
Dhar ...	Dhar Temple ...	22 35 51	75 19 27	......	W. End of City.
	Dharampuri Island Temp. ...	22 8 28	75 23 10		
	Kooksi Temp. ...	22 12 30	74 48 11		
	Mandoo Temp. ...	22 20 56	75 26 26	1,948	Close to Juma Musjid in Centre of Ancient City.
Dholepore	Dholepore Rana's Palace* ...	26 41 43	77 53 22		
Gwalior or Scindia.	Bhind Centre of Town	26 33 30	78 50 14		
	Deogarh ditto ...	26 5 0	78 37 8		
	Goona Residency ...	24 38 40	77 21 45	1,617	
	Gurmi Centre of Town	26 36 1	78 33 17		
	Gwalior Hill Temp.*	26 13 10	78 12 28		
	Kalianpoor Obs.* ...	24 7 12	77 41 45		
	Sepree Building in Fort ...	25 25 21	77 42 37		
	Sironj Fort Mosque*	24 6 23	77 43 37		
	Sironj Base N.-E. End Tower* ..	24 8 54	77 53 8		
	Sironj Base S.-W. End Tower* ...	24 4 47	77 47 53		
	Pagoda ...	23 11 8	75 50 32		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

CENTRAL INDIA AGENCY.—(*Continued.*)

DISTRICT.	PLACE.	Latitude.	Longitude.	Height above Sea.	REMARKS.
		° ′ ″	° ′ ″	Feet.	
HOLKAR ...	Augar Centre of Town	23 43 44	76 3 31		
	Bhikangaon ditto ...	21 52 1	76 0 19		
	Chikaldah Fort ...	22 4 59	74 55 48	461	
	Indore Palace* ...	22 43 6	75 53 49		
	Indore Residency* ...	22 41 25	75 55 12		
	Kasroad H. Temp. ...	22 7 41	75 39 17	664	
	Khargoon ...	21 49 34	75 38 57	898	Court-house.
	Mahesir ...	22 10 14	75 37 45	577	N. Doorway of Fort.
	Mandlesar Fort ...	22 10 20	75 42 19	520	
	Mehidpur Kotwali* ...	23 29 19	75 41 51		
JAWUD NEEMUCH ...	Jawud ...	24 35 54	74 54 16		
	Neemuch ...	24 27 38	74 54 15		
JHALRA PATAN.	Jhalra Patan City ...	24 32 4	76 12 44		
	Do. Cantonments ...	24 35 23	76 14 54		
JOWRA ...	Jowra Palace ...	23 38 16	75 10 4		
MYHERE ...	Myhere Palace ...	24 16 7	80 47 42		
NAGODE ...	Nagode Centre of Town	24 34 8	80 37 50		
PANNA ...	Panna City Survey Station ...	24 43 30	80 13 53	1,147	
REWAH ...	Bandogarh Fort ...	23 41 6	81 4 49		
	Burdi Town Centre...	24 32 36	82 25 0		
	Mowganj ditto ...	24 39 11	81 54 9		
	Rewah Palace ...	24 31 21	81 20 0		
	Sehaol Town Centre	24 33 38	82 16 28		
SOHAWAL ...	Sohawal Town Centre	24 34 13	80 48 21		

BERAR.

Hyderabad Assigned District.

DISTRICT.	PLACE.	Latitude.	Longitude.	Height above Sea.	REMARKS.
		° ′ ″	° ′ ″	Feet.	
AKOLA ...	Akola Centre of Town	21 5 50	77 6 10		
	Ballapoor, ditto ...	20 40 10	76 49 35		
	Julgaon Fort ...	21 2 59	76 34 35		
	Khamgam Centre of Town ...	20 42 25	76 37 15		
	Pathoor Centre of Town ...	20 27 20	76 59 20		
	Sheogam Centre of Town ...	20 47 43	76 45 8		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

BERAR.—(*Concluded.*)

District.	Place.	Latitude. ° ′ ″	Longitude. ° ′ ″	Height above Sea. Feet.	Remarks.
Bassim ...	Bassim Town ...	20 6 33	77 10 53		
	Mungrool Pir, do. ...	20 19 0	77 24 10		
	Oomerkher Temple on Hill ...	19 35 50	77 44 0	1,583	
	Pusad Town ...	19 54 40	77 37 20		
	Risod do. ...	19 58 28	76 50 10		
	Sirpur do. ...	20 10 35	77 0 30		
Booldana ...	Booldana Town ...	20 32 30	76 14 5		
	Deolghat do. ...	20 31 0	76 10 0		
	Loanar do. ...	19 59 8	76 33 40		
	Maiker do. ...	20 9 20	76 37 5		
	Mulkapoor do. ...	20 4 42	76 23 13		
Ellichpoor	Amnair Fort ...	21 31 43	76 49 36		
	Anjangaon Town ...	21 9 45	77 21 3		
	Chikalda Village Tree	21 24 0	77 21 33	3,773	
	Ellichpoor Cantt. ...	21 17 33	77 33 19	1,377	
	Gawilgarh Mosque ...	21 22 18	77 22 59		
Oomraoti ...	Badnera Town ...	20 51 46	77 46 35		
	Karuiji do. ...	20 28 33	77 31 50		
	Kolapoor do. ...	20 56 23	77 33 8		
	Moortijapoor do. ...	20 44 10	77 24 50		
	Oomraoti Katcheri ...	20 56 17	77 49 11	1,332	
	Talagao Fort ...	20 40 43	78 8 10	1,051	
Wun ...	Kalam Fort ...	20 26 39	78 22 4		
	Kota Fort ...	20 38 43	78 6 50		
	Wun Fort ...	20 3 7	78 59 50	863	
	Yeotmal Fort ...	20 23 32	78 10 36	1,584	

CENTRAL PROVINCES.

District.	Place.	Latitude. ° ′ ″	Longitude. ° ′ ″	Height above Sea. Feet.	Remarks.
Balaghat...	Hata Fort ...	21 43 15	80 18 51		
Betul ...	Badnur Town ...	21 54 28	77 56 40	2,173	
	Betul Katcheri ...	21 51 16	77 58 7	2,189	
	Multye ...	21 46 26	78 18 5	2,526	

LATITUDES AND LONGITUDES.—(*Continued.*)

CENTRAL PROVINCES.—(*Continued.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Bhandara...	Bhandara Katcheri ...	21 9 22	79 41 43	858	
	Mohari Town ...	21 18 25	79 43 5		
	Powni do. ...	20 47 26	78 41 9		
	Tumsal do. ...	21 23 0	80 47 50		
Chanda ...	Armori Town ...	20 28 50	80 1 26		
	Chanda Temp. ...	19 56 30	79 20 47	657	
Chindwara.	Chindwara Survey Station near Katcheri* ...	22 3 9	78 58 45	2,236	
	Deogarh Survey Station ...	21 51 51	78 45 31		
	Harai Town ...	22 36 53	79 15 57		
	Ludekhera do. ...	21 35 0	78 54 0		
	Pandhurna do. ...	21 35 40	78 34 0		
	Seoni do. ...	21 32 31	78 39 6		
	Sohagpur (Moti Mahal)* ...	23 19 5	81 23 42	1,530	
Damoh ...	Damoh Survey Station over Town*	23 50 20	79 29 15	1,385	
	Hatta Jail* ...	24 7 34	79 38 59		
Feudatory N. States	Bustar (old) Fort ...	19 12 30	81 59 15		
	Jagdalpur Town ...	19 5 22	82 4 0	1,831	
Hoshangabad ...	Hoshangabad Fort*...	22 45 48	77 45 5		
	Hardu Police Station	22 20 13	77 8 25	975	
	Pachmari Sanatarium Station ...	22 27 38	78 27 45	3,538	
	Seoni Town* ...	22 26 50	77 29 0		
	Sohagpoor* ...	21 52 16	78 1 27		
Jabalpoor...	Jabalpoor Deputy Commr.'s Katcheri*	23 9 58	79 59 30	1,306	
	Sleemanabad Temple*	23 38 32	80 17 57		
Mundla ...	Mundla Temple* ...	22 35 6	80 24 26	1,470	
	Ramgarh Town ...	22 47 37	81 0 5	2,570	
Narbada Narsingpoor	Narsingpoor Jail* ...	22 56 35	79 14 45		
Nagpoor Nagpur	Bela Town ...	20 46 35	79 3 54	1,236	
	Kamthi do. ...	21 13 15	79 13 41		
	Katola do. ...	21 16 30	78 38 1		
	Khapa do. ...	21 35 0	79 1 25		
	Mohpa do. ...	21 18 25	78 52 24		
	Nagpoor do. ...	21 9 10	79 9 0		
	Saoner do. ...	21 22 50	78 57 21		
	Sitabaldi ...	21 8 49	79 7 40	1,130	
	Umrer do. ...	20 51 10	79 22 4		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

CENTRAL PROVINCES.—(*Concluded.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Nimar ...	Asirgarh Fort Minaret	21 28 19	76 20 9	2,198	
	Burhanpoor Town ...	21 18 33	76 16 26		
	Khandwa do. ...	21 50 0	76 23 20		
Raipoor ...	Raipoor do. ...	21 14 43	81 41 11	994	
Sagar ...	Sagar Hill* ...	23 49 48	78 48 15	2,033	
	Do. Magazine* ...	23 50 9	78 46 51		
Sambalpoor	Sambalpoor Katcheri*	21 27 12	84 1 11		
Seoni (Chatisgarh)	Seoni Paka House ...	22 5 33	79 35 8	2,043	In City.
Upper Godavery...	Damogudiam Survey Station* ...	17 51 16	80 55 18	297	
	Seroncha Survey Station* ...	18 50 49	80 0 8	414	
Wardha ...	Arwi Town ...	20 59 45	74 16 16		
	Deoli do. ...	20 39 0	78 31 12		
	Hingunghat do. ...	20 33 30	78 52 34		
	Wardha do. ...	20 44 50	78 38 36		

HYDRABAD, NIZAM'S DOMINIONS.

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Amrabad ...	Amrabad Town ...	16 22 45	78 52 40		
	Attehampett do. ...	16 23 43	78 40 50		
Baithalwaddy.	Baithalwaddy do. ...	20 33 48	75 40 35		
Beder ...	Beder Base E. End*	17 54 49	77 34 21		
	Beder Base W. End*	17 53 32	77 39 27		
	Beder Minaret* ...	17 57 33	77 38 38		
Bheer ...	Bheer Town ...	18 59 30	75 48 50		
Bhonaghur	Bhonaghur do. ...	17 30 30	78 55 35		
Daolatabad.	Aurungabad do. ...	19 54 0	75 22 10		
	Daolatabad Fort ...	19 56 29	75 15 15		
Daroor ...	Daroor Town ...	18 49 18	76 9 38		
	Damargadi do. ...	18 8 16	77 42 31		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

HYDRABAD, NIZAM'S DOMINIONS.—(*Continued.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Daverconda.	Daverconda Town ...	16 42 15	78 58 0		
Eilgundel.	Eilgundel do. ...	18 26 3	79 4 49	1,153	
Ghunapoora.	Ghunapoora do. ...	16 33 50	78 5 20		
Golconda ...	Bolarum Church Tower* ...	17 30 59	78 33 57		
	Golconda ...	17 22 58	78 26 35	2,024	Height of Survey Station in Fort.
	Hydrabad Afzalganj Masjid N. E. Minaret* ...	17 22 26	78 31 4		
	Hydrabad Res. Flag Staff* ...	17 23 14	78 30 33	1,977	Lower Cross Piece.
	SecundrabadSt.John's Bell Tower* ...	17 26 33	78 32 55	1,791	Height of Cistern of Barometer on Meteorological Observatory.
Jaulna ...	Jaulna Cantonment...	19 50 48	75 55 48		
Koil Konda	Koil Konda Town ...	16 45 5	77 49 50		
Koolburga.	Koolburga do. ...	17 20 30	76 53 55		
Kowlass ...	Kowlass do. ...	18 20 10	77 44 10		
Kulleanee.	Kulleeanee do. ...	17 52 30	76 59 38		
Kummumett	Kummumett do. ...	17 14 48	80 11 10		
Mahore ...	Mahore do. ...	19 50 40	77 57 48		
Moodgul ...	Moodgul do. ...	16 0 40	76 29 0		
	Sindunoor do. ...	15 46 30	76 47 58		
Mudduk ...	Mudduk do. ...	17 41 30	78 19 28		
Mulkhair..	Mulkhair do. ...	17 11 28	77 12 8		
Mullangoor.	Mullangoor do. ...	18 17 55	79 22 28		
	Mullangoor Survey Station on hill ...	18 18 16	79 22 26	1,633	
Nelgoonda.	Nelgoonda Town ...	17 2 48	79 17 58		
Nuldroog...	Nuldroog do. ...	17 49 0	76 20 3		
Pangul ...	Pangul do. ...	16 14 40	78 10 28		
Patree ...	Patree do. ...	19 15 18	76 29 20		
Puraindа ...	Puraindа do. ...	18 16 5	75 29 46		
Pyton ...	Pyton do. ...	19 28 35	75 25 43		

* Obtained from Great Trigonometrical Survey Records

LATITUDES AND LONGITUDES.—(*Continued.*)

HYDRABAD, NIZAM'S DOMINIONS.—(*Concluded.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
RAICHOOR ...	Raichoor Town ...	16 11 53	77 23 28		
SHAHABAD...	Shahabad do. ...	17 9 50	78 10 56		
SUGGUR ...	Suggur do. ...	16 37 25	76 50 40		
WARUNGUL...	Warungul do. ...	17 57 30	79 39 28		
YEDAGHERI.	Yedagheri do. ...	16 46 0	77 10 53		

MADRAS PRESIDENCY.

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
ARCOT, NORTH.	Arcot Fort, Nabob's House* ...	12 54 16	79 22 31		
	Chittoor Village ...	13 13 0	79 8 16		
	Vellore Fort Pagoda*	12 55 7	79 10 42		
ARCOT, SOUTH.	Chitlapett Mosque* ..	12 27 59	79 23 50		
	Cuddalore Flag Staff*	11 43 24	79 49 6		
	Gingee Droog ...	12 15 19	79 26 8		
	Porto Nuovo Fl. Staff	11 29 25	79 48 13		
	Trinomalee Pagoda...	12 13 56	79 6 43		
	Verdachellum Highest Pagoda* ...	11 31 4	79 21 39		
BELLARY ...	Bellary Fort Survey Station* ...	15 8 57	76 57 12	1,976	
	Chennumpilly Droog Redoubt* ...	15 18 12	77 38 11		
	Durmavaram Fort Building* ...	14 24 35	77 45 50		
	Gooty Droog Flag Staff* ...	15 6 58	77 41 32		
	Todmurry Fort Cavalier* ...	14 33 47	77 53 50		
	Wudjar Curior Fort*	15 1 44	77 25 34		
CANNARA, SOUTH.	Coondapoor Town ...	13 38 20	74 44 1		
	Mangalore Fort Flag Staff* ...	12 51 40	74 32 38		
	Mangalore Lighthouse* ...	12 52 17	74 53 10		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

MADRAS PRESIDENCY.—(*Continued.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Chingliput	Chingliput Fort Flag Staff* ...	12 42 1	80 1 13		
	Madras Lighthouse*	13 5 11	80 19 53		
	Observatory Merdn. Station* ...	13 4 6	80 17 22		
	Madras St. George's Cathedral* ...	13 3 5	80 17 43		
	Madras St. George's Fort Flag Staff* ...	13 4 44	80 19 49		
	Madras St. Thomas' Fort Flag Staff* ...	13 0 18	80 14 11		
	Pulicat Church* ...	13 25 8	80 21 24		
	Ditto Lighthouse*	13 25 15	80 22 8		
Coimbatore.	Coimbatore Palace*...	10 59 41	76 59 46		
	Darapuram Fort Cavalier* ...	10 44 35	77 34 38		
	Karur Pagoda* ...	10 57 42	78 7 16		
Cuddapa ...	Cuddapa Judge's Court* ...	14 28 17	78 51 53	457	
	Cummum Town ...	15 33 45	79 9 1		
	Panganore, do. ...	13 21 50	78 35 46		
Ganjam ...	Russelconda* ...	19 55 39	84 36 23		
	Berhampoor, Mr. Phillip's House*...	19 18 15	84 51 14		
	Chatarpoor Tree* ...	19 21 20	85 1 22		
	Calingapatam Fl. St.*	18 20 36	84 9 59		
	Ganjam Fort Survey Station* ...	19 22 30	85 5 59		
	Gopalpore Bungalow*	19 13 0	84 56 29		
Godavery...	Ellore ...	16 42 55	81 9 6		
	Koringa Paka House*	16 48 40	82 15 55		
	Do. Lighthouse ...	16 49 5	82 20 0		
	Rajamandri ...	17 0 29	81 48 36		
	Dowleshwaran* ...	16 57 52	81 50 29		
Kistna ...	Condapillydroog Pagoda* ...	16 37 59	80 34 17		
	Guntoor Mosque Flag Staff* ...	16 17 51	80 29 45		
	Masulapatum Fl. St.*	16 9 8	81 11 38		
	Do. Fort Church...	16 9 0	81 11 29		
Kurnool ...	Kurnool Judge's Court	15 49 32	78 4 33		
Madura ...	Dindigul Flag Staff.*	10 21 39	78 0 17		
	Madura S. Guparam of Temple* ...	9 55 4	78 9 42		
	Ramagherry Hill Palace ...	10 38 13	78 9 47		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

MADRAS PRESIDENCY.—(*Concluded.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Malabar ...	Beypoor Saw Mill* ...	11 10 8	75 50 44		
	Calicut Flag Staff* ...	11 15 9	75 48 48		
	Cannanore Flag Staff*	11 51 12	75 24 44		
	Quilon Town ...	8 53 30	76 38 20		
	Telicherry Flag Staff*	11 44 53	75 31 38		
Nellore ...	Armugghan Light-house* ...	13 53 8	80 14 49		
	Nellore Church Tower* ...	14 26 38	80 1 28		
	Nellore Pagoda* ...	14 28 1	80 1 40		
	Oodagherri Droog Station* ...	14 51 56	79 19 5		
	Venkettygherri Pagoda ...	13 57 12	79 37 19		
Salem ...	Salem (Perria) Fort S. W. Angle* ...	11 39 10	78 11 47		
	Salem Railway Stn.*	11 40 9	78 9 21		
	Woomloor Fort Highest Cavalier*	11 44 10	78 4 40		
Tanjore ...	Nagore Flag Staff* ...	10 49 26	79 53 24		
	Negapatam Flag Staff* ...	10 45 37	79 53 28		
	Tanjore Great Pagoda* ...	11 1 37	79 53 44		
Tinnevelly	Palamcottah Fort Flag Staff* ...	8 43 33	77 46 11	119	Ground Level Top.
	Tinnevelly Pagoda Top* ...	8 43 39	77 43 51	213	
	Tutocorin Flag Staff	8 48 8	78 1 27		
Trichinopoly.	Trichinopoly Survey Station* ...	10 49 45	78 14 11		
	Trivelly Rock Pagoda*	10 57 26	78 42 33		
Vizagapatam ...	Bimlipatam Survey Station* ...	17 53 25	83 29 12		
	Chicacole Mosque N. Spire* ...	18 17 39	83 46 33		
	Chittiwaisa Sugar Factory* ...	17 55 55	83 29 38		
	Vizagapatam Fort* ...	17 41 34	83 20 12	......	Flag Staff.
	Vizianagram Raja's House* ...	18 6 55	83 26 47		
	Waltair Racket Court*	17 43 9	83 21 12		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

MYSORE PROVINCE.

DISTRICT.	PLACE.	Latitude.	Longitude.	Height above Sea.	REMARKS.
		° ′ ″	° ′ ″	Feet.	
BANGALORE	Bangalore Commr.'s Flag Staff* ...	12 58 52	77 38 4	3131	Height of roof of Observatory, S. E. of Base Line.
	Bangalore Palace ...	12 57 37	77 36 56		
	Do. Trinity Church*	12 58 18	77 39 46		
	Devanhally Village	13 15 0	77 45 21		
	Gulhalli Village Pagoda* ...	12 22 50	77 30 18		
	Magadi Village ...	12 57 0	77 15 26		
	Nelmangala do. ...	13 6 9	77 26 21		
CHITTALDROOG.	Chittaldroog Fl. St.*	14 13 45	76 26 0		
	Doderi Village ...	14 17 50	76 45 11		
	Herinjur do. ...	13 56 40	76 39 41		
	Molkálmuru do. ...	14 43 55	76 46 41		
HASSAN ...	Hassan Fort Survey Station* ...	13 0 15	76 8 15	3,150	
	Hernhalli Town ...	11 52 40	76 59 41		
	Maharaj Drug Hill, Temple* ...	12 53 25	75 56 41	3,899	
	Manjirabad Fort* ...	12 55 1	75 47 51	3,424	
KADUR ...	Kadur Fort* ...	13 33 13	76 2 50	2,559	
	Koppa Village ...	13 31 30	75 22 0		
	Vastara do. ...	13 16 10	75 45 36		
KOLAR ...	Ambaji Durga Survey Station* ...	13 33 36	78 8 33	4,399	
	Ambaji Durga Village ...	13 23 40	78 3 31		
	Betmangala Village	13 0 40	78 22 36		
	Chikballapur do. ...	13 26 0	77 46 11		
	Kolar do. ...	13 8 20	78 10 21		
TUMKUR ...	Chikmayakanhalli Village ...	13 25 15	76 39 51		
	Kortagere Village ...	13 31 30	77 16 31		
	Sira do. ...	13 44 50	76 57 0		
	Tumkur do. ...	13 20 5	77 8 16		
	Turuvekere do. ...	13 10 20	76 42 31		
MYSORE ...	French Rocks* ...	12 30 27	76 44 24	2,884	
	Maddur Village ...	12 35 30	77 5 11		
	Mailkotta Survey Station* ...	12 39 56	76 41 39		
	Mallavelli do. ...	12 23 10	77 5 51		
	Mysore Palace* ...	12 18 17	76 41 48		
	Seringapatam Tippoo Saib's Tomb* ...	12 24 35	76 45 22	2,282	

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

MYSORE PROVINCE.—(*Concluded.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Shimoga ...	Chamragiri Village Centre ...	14 1 10	75 57 41		
	Horiuali do. ...	13 20 0	76 25 21		
	Shimoga Fort Survey Station* ...	13 56 0	75 56 41	1,924	

COORG.

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Coorg ...	Mercara Fort* ...	12 25 11	75 46 53	3,804	

FOREIGN AND NATIVE STATES.

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Cochin ...	Cochin Flag Staff* ...	9 58 7	76 17 0		
	Trichur Town ...	10 32 0	76 15 18		
French Territory.	Karikal Town ...	10 55 20	79 52 21		
	Mahe do. ...	11 41 45	79 33 34		
	Pondicherry Fl. Staff*	11 55 57	79 52 33		
	Yanam Village ...	16 43 40	82 15 16		
Jeypur Feudatory State.	Jeypur Town ...	18 51 27	82 36 40		
	Kotpad do. ...	18 8 30	82 22 20		
	Kuraputi do. ...	18 48 20	82 45 50		
Tondeman...	Poodoocottah Town ..	10 37 0	78 51 51		
Travancore	Alepee Town ...	9 29 30	76 22 21		
	Cape Comorin* ...	8 4 0	77 35 41		
	Quilon Flag Staff*...	8 53 28	76 36 59		
	Trivandrum Great Pagoda* ...	8 29 3	76 59 9		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

N. W. PROVINCES.

District.	Place.	Latitude. ° ′ ″	Longitude. ° ′ ″	Height above Sea.	Remarks.
Agra ...	Agra Cantonment St. Paul's Church* ...	27 12 11	78 2 30		
	Agra Fort* ...	27 10 53	78 3 46	551	B. M. in Church Compound.
	" Tajmahal Dome*	27 10 26	78 5 4		
	Batesar* ...	26 56 6	78 35 7		
	Fatehpur Síkri* ...	27 5 35	77 42 18		
	Firozabad* ...	27 8 31	78 25 56		
	Kotla* ...	27 16 23	78 30 10		
	Pinhat* ...	26 52 56	78 24 50		
	Sikandra S. E. Minaret of Gateway* ...	27 [illegible]2 59	77 59 34		
Allahabad	Allahabad Fort Flag Staff* ...	25 26 0	81 55 15		
	Church Steeple* ...	25 27 43	81 54 12	298	Plinth of Sentry Box E. main entrance of Fort.
	Jhúsi Temple* ...	25 26 18	81 56 44		
	Sikundra* ...	25 35 15	82 1 5		
Aligarh ...	Alígarh Church* ...	27 54 0	78 7 0	606	B. M. opp. Encpg. Grd.
	Háthras Fort* ...	27 35 31	78 6 9		
	Koil City* ...	27 52 42	78 6 31		
	Sásni Town* ...	27 42 10	78 8 5		
Azamgurh	Azamgurh Church*..	26 3 2	83 13 20	256	Top of Sun Dial between Church and Kacheri.
	Chiriákot Town* ...	25 52 50	83 22 21		
	Ghosi do. * ...	26 7 10	83 35 41		
Banda ...	Banda* ...	25 28 18	80 22 4		
	Kankera Fort* ...	25 51 20	80 27 59		
	Sihonda* ...	25 17 0	80 23 51		
	Simauni* ...	25 35 30	80 38 51		
Bareily ...	Aliganj building* ...	28 20 20	79 17 41		
	Bareily Church* ...	28 22 5	79 28 3	560	B. M. Cant. Church.
	Futtehganj ...	28 27 0	79 21 0	572	
	Pelibhit* ...	28 38 4	79 50 35	613	B. M. in Masjid.
	Tanra* ...	29 4 17	79 28 15		
Basti ...	Amora Town ...	26 45 30	82 26 6		
	Basti do. ...	26 48 30	82 48 1	291	B. M. in Kacheri.
	Captainganj do.* ...	26 45 15	82 37 41		
Benares	Benares City ... Man Mandil or Hindoo Observatory*	25 18 26	83 3 12		
	Phariara Town ...	25 27 35	83 6 36		
	Mujhwasi do. ...	25 14 35	83 19 36		
	Sultanpoor Burial ground* ...	25 11 31	82 56 8		
	Sikraul Observatory*	25 20 2	83 1 43		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

N. W. PROVINCES.—(*Continued.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Bijnor ...	Afzalgurh Fort* ...	29 23 51	78 43 3		
	Bijnor Collector's house* ...	29 22 36	78 10 32		
	Najíbabad* ...	29 36 50	78 23 6		
Budaon ...	Debrai Fort* ...	27 50 33	78 44 58		
	Jalalabad* ...	27 43 20	79 41 23		
	Soro House* ...	27 53 30	78 47 20		
	Sahaswan* ...	28 4 22	78 47 16		
Boolundshahar ...	Begumabad* ...	28 10 53	77 35 32		
	Boolundshahar* ...	28 24 11	77 54 13	727	B. M. in Kacheri.
	Dadri Village ...	28 33 13	77 35 33		
	Kamona Fort* ...	28 7 46	78 9 14		
	Malagarh Fort* ...	27 27 51	77 52 17		
	Khurja* ...	28 15 20	77 53 51		
Cawnpore ..	Akbarpur Town ...	26 22 35	79 59 21		
	Bithur do. ...	25 36 40	80 19 1		
	Cawnpore Christ Church* ...	26 28 15	80 23 45	408	Top of stone tablet inscribed Cantonment Boundary, 1859.
	Ghátampur town ...	26 9 0	80 11 51		
Dehra Doon	Banog Observatory*..	30 28 30	78 3 23	7,452	
	Dehra Doon Base—				
	E. End* ...	30 17 1	78 0 58		
	W. End* ...	30 19 36	77 54 9	1,958	
	Gurudwara Temple*	30 19 5	78 4 27		
	Landour Catholic Chapel* ...	30 27 50	78 8 17	7,559	
	Landour Hospital*...	30 27 24	78 8 32	7,383	
	Mussooree Church* .	30 27 36	78 6 37	6,620	Height of Mussooree Library.
	Nalapani Kalinger Fort* ...	30 20 27	78 8 26		
	Rajpur D. B.* ...	30 23 50	78 8 25		
Etah ...	Etah Town ...	27 34 0	78 42 26		
	Kádirganj do. ...	27 48 30	79 6 21		
	Sirhpura do. ...	27 38 0	78 54 31		
Etawah ...	Barih Fort* ...	26 29 59	79 17 24		
	Etawah Old Fort* ...	26 45 31	79 3 18		
	Yani Fort* ...	26 27 36	79 23 10		
Farukhabad	Agosi Fort* ...	26 56 40	79 43 59		
	Chibrámau Thana*...	27 8 53	79 32 9		
	Farukhabad* ...	27 23 47	79 36 52		
	Fatehgarh Church*...	27 21 26	79 40 13		
	Jankat Fort* ...	26 51 25	79 54 5		
	Mahamdabad* ...	27 18 21	79 28 7		
	Nawábganj* ...	27 26 6	79 26 45		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

N. W. PROVINCES.—(*Continued.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Fatehpur...	Dhata Khas Village ..	25 32 20	81 16 36		
	Fatehpur do. ...	25 55 10	80 51 51		
	Haswa Village ...	25 52 10	81 16 36		
	Jehanabad* ...	26 6 2	80 24 18		
Garhwal ...	Badrinath Hill* ...	30 44 16	79 19 20	23,210	
	Kedarnath do.* ...	30 47 53	79 6 35	22,790	
	Paori* ...	30 9 25	78 47 49		
Ghazipur ...	Balia V. E., Tar Tree*	25 43 44	84 11 12		
	Ghazipur Church* ...	25 33 36	83 35 18		
	Ghazipur City Survey Station* ...	25 35 7	83 38 18	227	
	Ghazipur Lord Cornwallis' Monument*	25 33 30	83 35 19	226	4th Step. B. M.
	Ghazipur Opium Agent's Flag Staff*	25 34 25	83 37 9		
	Reotipur Village ...	25 32 20	83 45 11		
Gorakhpur	Deoria Town ..	26 30 0	83 48 31		
	Gorakhpur Jail* ...	26 44 44	83 23 37	225	B. M. in Church.
	Pipraich Town ...	26 49 50	83 35 21		
	Shahjahanpur do. ...	26 40 0	83 54 1		
Hamirpur...	Bardek Pillar on Jumna River* ...	26 22 19	79 31 50		
	Hamirpoor.*				
	Kalpi Fort Temp'e*	26 7 49	79 47 22		
	Pal Town* ...	26 14 45	79 38 48		
Jaloun ...	Atha Building* ...	26 2 35	79 38 53		
	Jagmanpoor Fort* ...	26 24 15	79 15 23		
	Jaloun* ...	26 8 32	79 22 42		
	Kotra Temple* ...	25 48 25	79 21 5		
Jhansi ...	Barwa Serai Town*...	25 22 39	78 46 46		
	Jhansi do.* ...	25 27 27	78 37 5		
	Oorai do.* ..	25 20 58	78 40 55		
Jaunpur ...	Bádsháhpur Town* ..	25 39 41	82 14 17		
	Jounpore Church* ...	25 43 48	82 44 7		
	Do. Fort* ...	25 44 53	82 43 49		
Kumaun ...	Almorah Commissioner's House* ...	29 35 10	79 41 16		
	Baramdeo* ...	29 6 15	80 11 37		
	Bhimtal* ...	29 20 37	79 36 11		
	Huldwani* ...	29 12 45	79 34 13		
	Kumaun Fort* ...	29 35 24	79 41 37		
	Pokri ...	29 44 55	79 58 54		
	Ranikhet Belfry ...	29 38 32	79 28 40	5,958	

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

N. W. PROVINCES.—(*Concluded.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Lalitpur ...	Lalitpur centre of Town ...	24 41 30	78 27 51		
	Máraura do. ...	24 22 45	78 50 51		
Mainpuri ...	Mainpuri Church* ...	27 14 14	79 8 6		
	Sakit Town* ...	27 26 7	78 49 15		
	Shikohabad do.* ...	27 6 6	78 38 7		
Muttra ...	Awa Chimney* ...	27 27 2	78 31 47		
	Brindaban Temple*...	27 33 33	77 44 0		
	Jalesar Town* ...	27 28 12	78 20 52		
	Muttra* ...	27 30 13	77 43 45		
Meerut ...	Bhatian* ...	28 39 23	77 47 21		
	Hápur Station* ...	28 43 20	77 49 33		
	Meerut Church* ...	29 0 41	77 45 3	735	B. M. in Church.
	Sardhana Church*...	29 8 47	77 39 32		
Mirzapur...	Bijaigarh Fort* ...	24 34 35	83 13 29		
	Bindhachal* ...	25 9 48	82 32 55		
	Chunar Fort Fl. St.*..	25 7 30	82 55 0		
	Lalganj* ...	25 0 48	82 23 51		
	Mirzapur Court House* ...	25 9 19	82 37 23		
Moradabad	Kasipur* ...	29 12 50	78 59 48		
	Moradabad* ...	28 51 1	78 48 36	655	B. M. in Church.
Muzafarnagar ...	Ferozepore* ...	29 30 1	78 1 1		
	Kaliana Observatory*	29 30 49	77 41 33	828	
	Mozafarnagar* ...	29 28 16	77 43 43	705	B. M. near Post Office.
Rampore Nat. State	Rampore Town ...	28 48 30	79 4 16		
	Shahabad do. ...	28 34 10	79 3 6		
Saharanpore ...	Deoband* ...	29 41 33	77 43 18		
	Hardwar* ...	29 57 36	78 12 52		
	Kankal* ...	29 55 44	78 11 38		
	Roorki* ...	29 51 55	77 56 18	905	
	Saharanpore Belleville pillar* ...	29 57 18	77 35 30		
	Sorsawa Building* ...	30 0 53	77 26 20		
Shahjehanpore ...	Shahjehanpore Fort Gateway East Minaret* ...	27 51 26	79 57 9		
	Shajehanpore Magistrate's and Collector's Office* ...	27 53 3	79 57 40	507	
	Rosa Sugar Factory*	27 49 18	79 57 27		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

OUDE CHIEF COMMISSIONERSHIP.

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Bara Banki	Haidargarh Town ...	26 36 10	81 24 25		
	Nawabganj do. ...	26 55 50	81 14 20		
	Ramnagar do. ...	27 5 15	81 27 40		
Bahraich ...	Bahraich Town ...	27 34 25	81 38 10		
	Ikauna do.* ...	27 31 52	82 0 45		
	Nándpára do. ...	27 32 5	81 32 50		
	Tulsipur do. ...	25 2 22	82 27 24		
Fyzabad ...	Ajudhya or Oude* ...	26 47 43	82 14 54		
	Bíkapur Temple* ...	26 46 44	82 11 59		
	Fyzabad Sooja Dowlas Tomb* ...	26 46 45	82 12 0	332	B. M. in Kacheri.
	Tánda House* ...	26 33 11	84 42 18		
Gonda ...	Atrowli Town ...	27 18 10	82 27 40		
	Bulrámpur do. ...	27 25 35	82 13 50		
	Colonelganj do. ...	27 7 55	81 44 30		
	Gonda do. ...	27 27 35	82 0 35		
Hurdoi ...	Bilgrám Town...	27 10 30	80 4 25		
	Hurdoi do. ...	27 23 15	80 9 30		
	Hasanpur Khás do. ...	27 15 5	81 39 20		
	Sandi do. ...	27 17 30	80 0 10		
Kheri ...	Dhaurahra Town ...	27 59 45	81 7 50		
	Kheri do. ...	27 54 0	81 50 25		
	Muhamdi do. ...	27 57 12	80 14 56		
Lucknow	Lucknow Cantonment Church* ...	26 54 31	80 58 50	364	B. M. Prot. Ch. in Civil Lines.
	Lucknow Constantia House* ...	26 50 19	81 0 19		
	Lucknow Observatory* ...	26 51 10	80 58 57		
	Lucknow Residency*	26 51 39	80 58 5		
	Malihabad Town ...	26 54 55	80 45 45		
	Mohanlalganj do. ...	26 40 50	81 1 30		
Pertabgarh	Bihar Town ...	25 41 35	81 39 45		
	Patti do. ...	25 35 30	82 14 50		
	Pertabgarh do. ...	25 33 30	81 59 5		
	Utcha do. ...	26 5 50	81 40 50		
Rae Bareli	Dattaoli Town ...	26 9 50	81 0 40		
	Rae Bareli do. ...	26 13 59	81 16 12		
	Salon do. ...	26 1 40	81 29 45		
Sitapur ...	Khyrabad Village ...	27 31 25	80 48 0		
	Láharpur do. ...	27 42 40	80 57 25		
	Maholi do. ...	27 39 50	80 30 55		
	Sitapur Town ...	27 34 20	80 42 55	447	B. M. in Katcheri.
	Tambour Village ...	27 43 50	81 12 10		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

OUDE CHIEF COMMISSIONERSHIP.—(*Concluded.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Sultanpur	Amethi Town...	26 9 30	81 50 45		
	Kadipur do. ...	26 9 52	82 24 40		
	Musáferkhana do. ...	26 22 40	81 50 25		
	Sultanpur do. ...	26 15 37	81 6 55		
Unao ...	Bangarmau Town ...	26 53 45	80 15 15		
	Purwa do. ...	26 27 25	80 49 5		
	Unao do. ...	26 47 45	80 43 10	412	O. & R. Rail Stn. top of middle of platform.

PUNJAB LIEUT.-GOVERNORSHIP.

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Amritsar ...	Amritsar* ...	31 37 12	74 45 11		
	" Gurudwara Spire* ...	31 37 16	74 55 3		
	Jandiala* ...	31 33 40	75 4 7		
	Vhairowal* ...	31 25 9	75 12 38		
Bunnu ...	Billote Mosque* ...	32 15 22	71 11 51		
	Bunnu Fort, Edwardsabad* ...	32 59 45	70 38 51		
	Isakhel* ...	32 40 50	71 19 0		
	Kálábagh Tower* ...	32 57 57	71 35 37		
	Miánwali Mosque* ...	32 34 33	71 32 52	681	
	Ramani Kheyt Village* ...	32 23 55	71 12 50		
	Shekh Boodeen Hill*	32 17 49	70 50 49	4,516	
Delhi ...	Balabgarh Town ...	28 20 15	77 21 36		
	Delhi Fort* ... / Juma Musjid Dome	28 38 58	77 16 30		
	Delhi Humayoon's Tomb* ...	28 35 31	77 17 34		
	Tuglukabad* ...	28 32 20	77 22 16		
	Kootub Minar* ...	28 31 23	77 13 35		
	Sonput Town ...	28 59 30	77 3 36		
Dehra Ghazi Khan.	Asni Mosque* ...	29 1 16	70 17 37		
	Dájal T. S. ...	29 33 22	70 25 21	412	B. M.
	Dehra Ghazi Khan...	30 3 57	70 49 8	395	B. M. East of Katcheri.
	Harrand Fort* ...	29 32 48	70 9 52		
	Jampúr Town* ...	30 38 34	79 38 4		
	Mithankot Tomb* ...	28 55 24	70 25 6		
	Rájunpore House* ...	29 6 7	70 21 57		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

PUNJAB LIEUT.-GOVERNORSHIP.—(*Continued.*)

DISTRICT.	PLACE.	Latitude.	Longitude.	Height above Sea.	REMARKS.
		° ′ ″	° ′ ″	Feet.	
DEHRA ISMAEL KHAN	Bhakar Town* ...	31 37 43	71 5 52	579	
	Dárában do. * ...	31 47 38	71 8 55		
	Dera Ismail Khan*	31 50 37	70 55 44	......	Akalgarh Fort Flag Staff.
	Kúlachi Town* ...	31 55 38	70 30 19		
	Leia do. * ...	30 57 33	70 58 21		
FEROZEPORE	Ferozepore Magazine*	30 56 42	74 38 24		
	Ferozepore Gun Foundry Chimney* ...	30 55 14	74 39 40	645	B. M. near Horse Artillery Lines.
	Mamdote Town* ...	30 52 17	74 27 26		
GUJRANWALA.	Gujranwala Town ...	32 9 30	74 14 0		
	Jalalpur* ...	32 3 55	73 25 23		
	Pindi Bhatian* ...	31 54 5	73 18 53		
	Shekopura Town ...	31 43 0	74 2 0		
	Wazirabad do. ...	32 26 50	74 9 41		
GUJRAT ...	Chilianwala Monument* ...	32 39 46	73 38 52		
	Gujrat* ...	31 26 52	75 14 8		
	Jalalpur Town ...	32 21 35	74 15 1		
	Kharian do. ...	32 58 45	73 54 21		
	Phatian do. ...	32 25 45	73 37 21		
GURDASPUR.	Battala* ...	31 48 33	75 14 32		
	Gurdaspur* ...	32 2 40	75 27 0		
	Pathankote* ...	32 16 39	75 41 48		
GURGAON	Firezpur Palace* ...	27 47 8	76 59 41		
	Gurgaon ...	28 37 30	77 4 0		
	Hodal Building* ...	27 53 24	77 24 35		
	Rewari Temple ...	28 11 52	76 39 32		
HAZARA ...	Abbottabad Town ...	34 9 5	73 15 28	4,166	
	Amb do. ...	34 18 30	72 53 40		
	Haripur do. ...	33 59 50	72 58 15		
	Mansera do. ...	34 20 10	73 14 28		
	Torbela do. ...	34 2 0	72 51 4		
HOSHIARPUR	Gurrshankar* ...	31 12 58	76 11 2		
	Hoshiarpur ...	31 32 13	75 57 17	1,141	
	Mukerian ...	31 56 53	75 38 52	990	
HISSAR ...	Barwala Town* ...	29 22 9	75 57 6		
	Hansi do. * ...	29 6 19	76 0 19		
	Hissar do. * ...	29 9 51	75 45 55		
	Narnaoud do. ...	29 13 14	76 11 22		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

PUNJAB LIEUT.-GOVERNORSHIP.—(*Continued.*)

District.	Place.	Latitude. ° ′ ″	Longitude. ° ′ ″	Height above Sea. Feet.	Remarks.
Jhang ...	Chiniot H. S.* ...	31 43 32	73 0 59	849	
	Haveli Town* ...	30 22 21	73 59 43		
	Jhang do.* ...	31 16 16	72 21 45		
	Mághiana do.* ...	31 16 41	72 20 56		
	Shorekot do.* ...	30 49 59	72 6 42		
Jhelum ...	Chakuwal Town ...	32 55 50	72 54 0		
	Jhelam* ...	32 55 26	73 46 36		
	Pind Dádan Khan ...	32 35 0	73 5 21		
	Talagang ...	32 55 30	73 27 31		
	Rhotas Fort* ...	32 57 48	73 36 56		
Jullundur..	Jullundur ...	31 19 50	75 37 20		
	Kaparthulla* ...	31 23 0	75 25 11		
	Kartarpoor* ...	31 26 39	76 32 28		
	Phillour Fort* ...	31 0 38	75 49 57		
	Rahoon sq. buildg.*...	31 2 59	76 9 23		
Kangra ...	Bhagsu* ...	32 12 23	76 21 44	4,742	
	Dharmsala* ...	32 15 42	76 22 46	9,280	
	Hurripore Fort* ...	30 46 35	77 34 47		
	Joala Mookhi ...	31 52 34	76 21 59	1,883	
	Kangra Fort* ...	32 5 14	76 17 46	2,494	
	Ditto Comr. House*	32 5 58	76 18 35		
	Noorpore* ...	32 18 11	75 55 27	2,125	
	Pathankote* ...	32 16 39	75 42 44		
Karnal ...	Karnal Church* ...	29 42 17	77 1 45		
	Kaithul Town* ...	29 48 7	76 26 26		
	Pánipat do. ...	29 23 0	77 1 11		
Kohat ...	Kohat Fort* ...	33 35 35	71 28 43		
	Lukki Town ...	32 36 45	70 57 6		
Lahore ...	Anarkulli* ...	31 35 17	74 21 4		
	Hariki Ghat* ...	31 9 35	74 59 25		
	Kasur* ...	31 6 46	74 30 31	673	Height of B. M. in Asst. Commr.'s Katcheri.
	Lahore* ...	31 34 5	74 20 59		
	Mian Mir* ...	31 31 15	74 25 14	709	Height of Church Door.
	Shahdara* ...	31 37 22	74 20 42		
Ludiana ...	Aliwal Town ...	30 57 10	76 39 0		
	Jagraon do. ...	30 47 20	74 55 16	765	
	Ludiana* ...	30 55 25	75 53 34	806	Height of B. M. near junction of Ferozepore and Umballa Roads.
	Moodki do. ...	30 47 0	74 55 16		
	Tehara* ...	30 56 1	75 26 48		
Montgomery.	Chichawatni D. B.*	30 34 10	72 43 41		
	Haveli* ...	31 4 11	72 31 21		
	Harappa* ...	30 37 40	72 54 44		
	Montgomery ...	30 58 0	73 21 0		Googaira Town.
	Pakpattan T. S.* ...	30 20 40	73 25 50	670	

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

PUNJAB LIEUT.-GOVERNORSHIP.—(*Continued.*)

District.	Place.	Latitude. ° ′ ″	Longitude. ° ′ ″	Height above Sea. Feet.	Remarks.
Mooltan ...	Kahror Town	29 37 0	71 57 41		
	Mooltan*	30 11 58	71 30 47	408	Height of Railway Station Platform.
	Sher Shah*	30 6 8	71 21 50		
	Shujabad*	29 53 0	71 20 0		
	Talamba Town	30 31 10	72 17 16		
Muzaffar-gurh.	Dera Dinpanáh*	30 34 2	70 58 35	490	
	Kot Adú*	30 28 14	71 0 30		
	Muzaffargarh*	30 4 32	71 13 57	386	Height of Pillar near Tahseel.
	Sunawan Town	30 19 0	72 1 0		
Peshawur..	Hoti Mardan Town...	34 11 15	72 6 0		
	Michni Fort ...	34 11 10	71 28 51		
	Naoshera Cantonment	33 59 50	72 1 10		
	Peshawar* ...	34 1 47	71 36 41	1,165	
Rawul Pindi	Attok Fort* ...	33 53 29	72 17 53	1,193	
	Hasan Abdal* ...	33 48 56	72 44 41		
	Murree* ...	33 54 30	73 26 32	7,518	
	Rawal Pindi* ...	33 37 4	73 5 57	1,707	
	Mankiala Tope* ...	33 26 55	73 17 7	1,959	
	Chuch Base E. end*	33 57 8	72 32 2	1,053	
	W. end* ...	33 53 12	72 26 21	1,018	
Rohtak ...	Bahadurgarh Town...	28 40 40	76 57 11		
	Jhajjar do.*...	28 36 33	76 41 10		
	Rohtak do.*...	28 53 43	76 38 7		
Shahpur	Khushâb Town ...	32 17 40	72 23 51		
	Mitha Tawana do. ...	32 14 40	72 8 51		
	Sakesar Hill Survey Station* ...	32 32 35	71 58 37	4,994	
	Shahpur Civil Station	32 16 0	72 31 0		
Sealkote ...	Daska Town Centre...	32 20 0	74 24 6		
	Sealkote Large Church*	32 31 15	74 36 21		
	Sumrial Town	32 28 20	74 23 41		
Simla	Dagshaie*	30 53 5	77 5 38		
	Kalka D. B.*	30 50 21	76 58 57		
	Kasuli*	30 53 13	77 0 52	6,410	
	Simla Church*	31 6 13	77 12 49	7,159	
	Simla old Magnetic Observatory*	31 6 12	77 11 0		
	Subathu*	30 58 27	77 1 55		
Sirsa	Fazilka*	30 34 57	74 4 10		
	Malaot*	30 10 46	74 31 16		
	Sirsa Town*	29 32 15	75 6 51	589	B. M. near Katcheri.

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

PUNJAB LIEUT.-GOVERNORSHIP.—(*Concluded.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Umballa ...	Belaspur* ..	30 18 47	77 20 46	924	B. M. Chowkey opposite encamping ground.
	Rooper* ..	30 51 45	76 38 46		
	Nahan* ..	30 39 49	77 20 16		
	Sirhind Mosque* ..	30 39 9	76 36 6		
	Thanesar* ..	29 58 37	76 52 13		
	Umballa* ..	30 21 25	76 52 14	902	B. M. W. doorway of Church.
Bhawalpore N. State.[1]	Ahmedpur B. M.* ..	29 8 37	71 18 17	348	
	Bhawalgurh Town*..	30 9 54	73 31 55		
	Bhawulpoor* ..	29 23 45	71 43 6	......	House in City.
	Bhawulpur * ..	29 22 52	71 41 40	375	B. M. 1½ miles W. of Town.
	Gaospur Dome* ..	28 51 32	70 34 41		
	Khanpoor Town* ..	30 8 41	71 15 58		

PROTECTED SIKH STATES.

Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″		
Tohanna	29 42 42	75 56 38		
Nirwana	29 35 58	76 9 34		
Kathana	29 33 3	76 25 49		
Jhind	29 19 12	76 21 23		
Nabha	30 22 31	76 11 36		
Dadree	28 35 31	76 18 54		
Loharoo	28 25 49	75 51 11		
Bhewanee	28 47 33	76 10 48		
Narnaol	28 2 26	76 8 53		
Kot Kassim	28 1 42	76 45 29		

RAJPUTANA AGENCY.

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
			° ′ ″	Feet.	
Ajmere ...	Ajmere (Taragarh Fort)* ...	26 26 30	74 39 31		
	Ajmere Residency Bungalow ...	26 26 42	74 41 54		
	Deoli* ...	25 45 39	75 24 57		
	Nasirabad Temple ...	26 17 43	74 47 43	......	East of Cantt.
	Do. Windmill ...	26 17 59	74 39 44		
	Nyanagar Church ...	26 6 11	74 21 23	1,495	

[1] Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

RAJPUTANA AGENCY.—(*Continued.*)

District.	Place.	Latitude. ° ′ ″	Longitude. ° ′ ″	Height above Sea. Feet.	Remarks.
Bhurtpore	Bhurtpore Palace* ...	27 13 10	77 32 12		
	Ditto Residency*	27 11 20	77 29 8		
	Biana* ...	26 53 12	77 16 40		
	Hindaon* ...	26 43 48	77 4 53		
Bikanir ...	Bikanir* ...	28 1 19	73 21 34		
	Bhatnur* ...	29 35 9	74 22 1		
	Nagour* ...	27 12 5	73 47 1		
Boondi ...	Boondi* ...	25 26 55	75 40 38		
	Indargarh Town ...	25 43 48	76 13 50		
	Patan ...	27 48 26	76 0 53		
Bundlecund	Nowgong* ...	25 3 30	79 31 0		
Dholpore...	Dholpore* ...	26 41 40	77 53 22		
	Deeg* ...	27 28 42	77 22 3		
	Duttia* ...	25 40 13	78 29 35		
	Machkunda Highest Building* ...	26 41 1	77 54 38		
	Panchgaon Building*	26 43 2	77 53 15		
Godwar ...	Erinpoora Hospital* .	25 8 56	73 5 56	869	
	Do. Marwar Agency .	25 8 46	73 6 0	876	
Jesalmir ...	Jesalmir Fort* ...	26 54 46	70 57 17	959	Highest building.
Jeypore ...	Ambair* ...	26 58 53	75 53 13		
	Jeypore* ...	26 55 28	75 51 46		
	Sambhar* ...	26 54 49	75 13 39		
Jhalawar ..	Jhalra Patan Highest Temple* ...	24 32 4	76 12 44		
	Ditto Cantonments* .	24 35 23	76 14 54		
Jodhpore ...	Jodhpore Fort* ...	26 17 43	73 3 36	......	Highest building.
Kerowlee..	Kerowlee* ...	26 29 43	77 4 20		
	Machilpore Town ...	26 37 50	77 16 28		
Kota ...	Kota Fort* ...	25 10 27	75 52 20		
	Nahargarh Fort* ...	24 55 14	76 58 7		
	Sultaupore.				
Oodeypore.	Chittore* ...	24 53 31	74 41 30		
	Oodeypore* ...	24 35 19	73 43 23		
Patan ...	Patan* ...	27 48 26	76 0 53		

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

RAJPUTANA AGENCY.—(*Concluded.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet	
Shekawatee.	Jhunjhuno* ...	28 7 39	75 25 38		
	Surujgarh* ...	28 18 45	75 46 26		
Sirohi ...	Mount Aboo* ...	24 35 37	72 45 16		
	Chittore* ...	24 53 31	74 41 30		
	Erinpoora* ...	25 8 26	73 6 21		
	Sirohi* ...	24 53 12	72 54 28		
Tonk ...	Tonk* ...	26 10 42	75 50 6		
Ulwar ...	Dousa* ...	26 53 25	76 22 53		
	Ghazi Kathana* ...	27 23 59	76 21 41		
	Harsaoli* ...	27 51 49	76 39 47		
	Lachmangarh* ...	27 21 47	76 53 59		
	Malakhera* ...	27 23 10	76 40 11		
	Tijara* ...	27 55 40	76 53 39		
	Ulwar* ...	27 34 27	76 37 45		

INDEPENDENT NATIVE STATES

Beyond British Territory.

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Bootan ...	Paro Town ...	27 23 20	89 28 0	7,741	
	Panakha do. ...	27 32 10	89 53 0	4,534	
	Tsangbi ...	27 8 0	89 10 30	6,143	
Kashmere ..	Akhnoor Baradari*	32 53 49	74 46 57	1,142	
	Astor Fort* ...	35 21 19	74 54 17	7,852	
	Basaoli Tower in Fort* ...	32 30 12	75 51 46	2,170	
	Chowmukh Temple*..	33 17 39	75 46 43	1,202	
	Dras Fort, Centre of N. Wall ...	34 25 49	75 47 33	10,144	
	Jummo Great Temple*	32 43 52	74 54 14		
	Kishtawar Fort* ...	33 18 38	75 48 22		
	Leh Fort* ...	34 9 30	77 36 43	11,280	
	Mirpur Temple* ...	33 11 4	73 49 19	1,236	
	Mozufferabad Fort*..	34 22 58	73 30 24		
	Rajaori Musjid* ...	33 23 8	74 21 49		
	Skardo Temple* ...	35 18 17	75 49 51		
	Srinagar Hari Parbat S. Bastion* ...	34 6 19	74 51 27		
Nepaul ...	Katmandu ...	27 41	85 18		
	Janoo Snowy Peak *	27 40 56	88 5 13	25,304	
	Mount Everest do.*...	27 59 17	86 58 6	29,002	
	Dhyabung do.* ...	28 15 22	85 33 35	23,762	

* Obtained from Great Trigonometrical Survey Records.

LATITUDES AND LONGITUDES.—(*Continued.*)

INDEPENDENT NATIVE STATES

Beyond British Territory.—(Concluded.)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Sikkim ...	Gipmoochi Snowy Peak* ...	27 16 26	88 56 37	14,518	
	Kanchanjinga Snowy Peak* ...	27 41 30	88 11 50	27,815	
	Tumlong Town ...	27 23 50	88 37 35	6,000	

* Obtained from Great Trigonometrical Survey Records.

N.B.—All the Longitudes in the foregoing lists are referrible to the Old value of the Madras Observatory, viz. 80° 17′ 91″ to which a correction of — 3′ 15″ is required to reduce to the results of Captain Jacob's determination.

LATITUDES AND LONGITUDES OF PLACES BEYOND INDIA.

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Ceylon British.	Colombo ...	6 56 6	79 49		Raper's Navigation, 1864.
	Point De Galle ...	6 1 48	80 13		
	Trincomalee ...	8 33	81 14		
	Adam's peak ...	8 52	80 29	7,000	
Malacca British.	Malacca Fl. St. ...	2 10 30	102 14 12		Ditto.
Penang British.	Penang, George Town Fort Cornwalis Fl. Staff ...	2 25 6	100 19 42		Ditto.
Singapore British.	Singapore Battery ...	1 17	103 50		Ditto.
Afghanistan.	Herat ...	34 22	62 8	2,650	Col. Walker's Map of Turkestan, May 1875.
	Balkh ...	36 32	66 46	1,800	
	Kandahar ...	31 37	65 30	3,490	
	Kabul ...	34 30	69 5	6,400	
	Ghuzni ...	33 34	68 19	7,730	
	Chetral ...	35 46	71 40	7,140	
	Jelalabad ...	34 24	70 26	1,950	
Beloochistan	Khelat ...	28 53	66 28	6,700	Ditto.
	Shalkot or Quettah	30 12	66 55	5,580	
Burma Independent.	Bhamo ...	24 18	96 58		Col. Yule's Map, 1857.
	Maudalay ...	21 55	96 10		

LATITUDES AND LONGITUDES OF PLACES BEYOND INDIA.—(*Continued.*)

District.	Place.	Latitude.	Longitude.	Height above Sea.	Remarks.
		° ′ ″	° ′ ″	Feet.	
Persia ...	Astrabad ...	36 51	54 28	377	Col. Walker's Map of Turkestan, May 1875.
	Bushahir or Bushire	29 9	50 50		
	Ispahan ...	32 38	51 40		
	Teheran ...	34 42	51 25	3,810	
	Shiraz ...	29 36	52 31		
Thibet ...	Lhassa ...	29 39 17	90 59 43	11,707	From Col. Montgomerie's Explorations by Pundits, &c.
	Shigatze (Tashymbo)	29 17	88 47	11,822	
	Gartok ...	31 44 4	80 23 33	14,250	
	Chumalari Snowy Peak* ...	27 49 42	89 18 43	23,944	
	Donkiah Snowy Peak*	27 56 57	88 53 5	23,816	
Eastern Turkestan.	Khokand ...	40 33	70 57	1,540	Col. Walker's Map of Turkestan.
	Aksu ...	41 9	79 39		
	Kashgar(Yangishahar)	39 24 32	76 6 48		Capt. Trotter's value by Observation.
	Yarkand ...	38 20	77 30	3,923	From Col. Montgomerie's Explorations.
	Ilchi (Khotan) ...	37 7	79 24	4,490	
	Pamir Lake or Barkut Yassen ...	37 14	74 18	13,300	
	Sirikul (Tashkurgaon)	37 44	75 13	11,000	

Obtained from Great Trigonometrical Survey Records.

DR. HUNTER'S RULES FOR THE SPELLING OF INDIAN PROPER NAMES.

No system of transliteration will accurately represent all the modifications of Indian letters in the various parts of the country. For the same letter has a very different pronunciation in different Provinces. Thus, the Bengali mouth refuses to form the consonant *v* and pronounces it *b*; for example, *Varuna* becomes *Barun*; *Siva* becomes *Siba*. In the same way the vowel *a* has various degrees of softness in different parts of India; thus the Uriya lengthens out the word *Rája* into *Rauja*, just as Sir Walter Scott makes his Perthshire characters lengthen out *Waverley* into *Wauverley*.

But for all practical purposes of transliteration, the following system, finally authorized by Government in 1870, suffices :—

आ Long *á* (as in *bhát*, rice) corresponding to the first *a* in *tartan*, *almond*, &c., and is represented by *á*

अ Short *a* (as in *man*, mind,) has a varying degree of broadness from the sound of the second syllable in woman, rural, to that of the first syllable in paltry. It is represented by *a*.

इ ई The long and short *i* (as in *til*, oil-seed, and *bíj*, seed,) need not, except on rare occasions, be distinguished unless in Urdu words. The sound varies from the sharp *i* in clique or police to the longer *i* in ravine. It is represented by *i*, with the accented *í* for the long Urdu sound when it is necessary to distinguish it.

उ ऊ Short and long *u* (as in *putra*, son, and *dúr*, distance,) need not, except in rare instances, be distinguished. It corresponds to the sounds of varying length in bull, put, and the first syllable of cruel, rural. It is represented by *u*, with the accented *ú* in the few words that may require accentuation. Thus, the word or termination *pur*, a city, need never be accented; as although it is long when written in the Persian character, it is short when written in the Nagari or Bengali.

ए *e* (as in *ek*, one,) corresponds to the English *ate*, in *madare*, or the French *é* in *méchant*, and is represented by *e*.

ओ *o* (as in *kot*, a fort,) corresponds to the English in *note*, *lore*, and is represented by *o*.

ऐ *ai* (as in *maidan*, a plain,) nearly corresponds to the English vowel sound in *ride*, *size* (but is broader), and is represented by *ai*.

औ *au* (as in *Gaur*) corresponds to our English vowel sound in *cloud*, and is represented by *au*.

The Government of India having, on the 28th February 1870, authorized the adoption of a uniform system of spelling for the Gazetteers and Maps, it became necessary in the first place to ascertain the true orthography of Indian Geographical Names. The system of spelling thus definitively promulgated is fully explained in my Plan for an Imperial Gazetteer and in the other documents noted below.* An outline of it will be found in the

* Letter from W. W. Hunter, Esq., to the Secretary to the Government of India, Home Department, dated Mirat, 9th September 1869, and published with Government orders thereon in the *Gazette of India* of the 31st May 1870. Also in the Instructions drawn up by me for the Editors of the Provincial Gazetteers, dated Simla, 9th November 1871, paras. 61-70.

Rules for the Orthography of Indian Proper Names, which precede this NOTE. It practically consists of the principles of transliteration advocated by Sir William Jones a hundred years ago, but modified so as to suit the exigencies of Cartography, and to make allowance for that considerable class of Indian places which have by lapse of time obtained a historical or popular spelling too firmly fixed to be now wholly changed. During the past two years I have endeavoured, by means of the Gazetteer operations, to obtain the exact orthography of all geographical names in Bengal, Orissa, Oudh, the Panjáb, the Central Provinces and the Berars. Side by side with these efforts, but by a distinct set of machinery, I have collected the accurate spelling of the whole 2,186 postal towns and villages throughout India. In 1869, after consultation with the Director-General of Post Offices, I found it possible by means of a system of circulars and returns to obtain the orthography of each such town or village correctly spelt in the vernacular of the district, and verified by the local Postmasters. The work of collecting, verifying, and transliterating has occupied all the time which I could spare from my other duties since 1869, and the result is now presented to Government.

The subject has been so exhaustively deliberated upon by Government, and I have already written on it at such length, that a very few remarks will suffice here. It is not too much to say that among the following names there are at least fourteen hundred, each one of which would admit of an elaborate discussion. For, besides those to which popular English usage has given a certain degree of fixity, an interminable series of considerations and difficulties arise from the fact that native usage, in many parts of the country, differs from the correct philological spelling. Thus, to take a few examples in the first place, of how English usage affects the question. It would be simple pedantry to attempt to alter a single letter in the names of Bengal, Bombay, Madras, or Calcutta; although the natives to this day write them as Bángálá (or in Urdu Bangálá), Mumbai, Mandráj, and Kalikatá. On the other hand, it is perfectly practicable to spell Punjab correctly as Panjáb, and British Burmah correctly as British Barmah. Both of these provinces are at present spelt in either way, and now that Government has definitively adopted a uniform system of spelling, they may invariably be spelt in the correct way. There is also a large class of more doubtful cases, such as Roy Bareilly, Lucknow, and Cawnpur. The first of these names furnishes a type of a numerous family in which Keith Johnston's Royal Atlas comes to our aid. The old Anglo-Indian form was Roy Bareilly; the mode to which Dr. Keith Johnston's map has given popular fixity in England is Rai Bareilli; and from this, the change to the correct form, namely Rai Bareli, is so slight that I have not hesitated to make it. On the other hand, the word Lucknow, being the capital of a province, and having obtained a historical fixity of spelling from the events of the Mutiny, I have not ventured to alter it into the correct form Lakhnau, or any modification of it, although Dr. Keith Johnston deemed this practicable. The third of the above examples, Cawnpur, is also a representative word. Its spelling in the vernacular is variously returned as Khánpur and Kanhpur (the latter being a contraction of Kanháipur, meaning Krishnapur). Dr. Keith Johnston gives in his map the two forms Kanhpur and Cawnpur. I have not ventured to go further than the latter form. In the same way, with regard to a large class of words, such as Lahore, Mysore (Malsúrú), Vellore (Vellúrú), &c., I have confined myself to striking out the final *e*, which would, according to the now authorized orthography, be sounded, and have spelt the words, Lahor, Mysor, Vellor. Throughout, I have most carefully avoided anything like the destruction of the identity of the word by a change in the spelling. In one or two cases, the present Post Office Guide simply mistakes the word. For example, it gives Sleemabad for what is in reality Sleemanabad, and Ramoona for what is in reality Rebná. Such mistakes occur only in the names of very unimportant places, and I have not hesitated to correct them. Thus, to continue the mistake of Sleemabad would be to destroy the history of the name, and its connection with Colonel Sleeman, after whom it is called.

But the difficulties arising from the unregulated Anglo-Indian usage which has hitherto prevailed in spelling geographical names, are few compared with those to which the local varieties of native usage give rise. Although the new system will encounter its most violent opposition—indeed, I believe its only opposition—from local Anglo-Indian writers, yet the total number of words around which such opposition could spring up, do not exceed two hundred out of the 2,186 postal towns in the following list.

The difficulties of an accurate recension of Indian geographical names lie much deeper. The natives themselves do not uniformly spell the same word in the same way. This arises partly from the differences in local usage which may naturally be expected in a vast continent like India, equal in size to all Europe, excepting Russia. But the principal variations occur from the circumstance that almost every province has not only a separate language, but a distinct set of letters of its own. The vernacular returns from which I have transliterated the following list of names are written in no fewer than ten different characters. Of these, one, the Urdu, follows the Persian alphabet; eight are long separated descendants of the Deva-Nágarí, *viz.*, Hindi (or current Nágarí), Bengali, Uriyá, Panjábí, Gujráthí, Marháthí, Támil, and Telugu; with regard to the tenth, Barmese, I do not venture to pronounce an opinion. Several of these languages have letters which do not exist in others. For example, the Uriyá has the old Sanskrit compound vowel *lr*, which does not exist in Hindi; the Bengali uses *b* and *v* indifferently; and the Támil has a complicated set of difficulties of its own. As I am not sufficiently acquainted with the current hand of all these different alphabets, the local Postmasters were instructed to write each word not only in the vernacular, but also in Persian or Hindi. I found that in many cases the word was differently spelt by the same writer in the two characters, and what would have been an accurate transliteration from one of them, would not have been a correct transliteration from the other.

This, however, only represents the initial difficulty in the undertaking. The multiform vernaculars of India differ not only as regards their written character, but they exhibit a most perplexing series of vowel and consonant changes, and of terminal variations. For example, the Bengali mouth refuses to form *v*, and invariably pronounces it as *b*. The Assamese and the whole Eastern peasantry soften *ch* into *s*, and *s* into *h*. Thus, they pronounce the principal frontier town of Assam as Saikhoá, while the Bengali pronounces it as Chaikhoá;* and the god Siva of Northern India becomes Siba in Bengal and Hiwa in Assam. Again, while the Persian character and the Urdu tongue have a perfect affluence of letters to represent the sound of *z*, having indeed five different characters for it, the Nágarí-descended languages know nothing of this consonant, and have no letter to represent it. Yet the Persian and Urdu races have given names to places in every province of India, and whenever one of these names contains any of the five forms of *z*, the sound has to be roughly represented by *j*. In the Dissertation to my Non-Aryan Dictionary, I explained the interchanges and phonetic vagaries of *l*, *r*, and the sibilant. It frequently appears in the place of *r* in names of towns. Thus, for example, the postal village Káyalpatam is also pronounced and spelt Káyarpatam. The same class of difficulties rise up around *b* and *p*, the soft Indian *d* and *r*, &c.

But it is the vowel interchanges which have given me most trouble. The elaborate Sanskrit system of *Sandhi* finds free play amid the various dialects which now separate India into linguistic jurisdictions. Where one vernacular would use *u*, another uses *o*, a third *au*, a fourth *v*, a fifth *w*, and a sixth *b*, which has a chance of ultimately becoming *p* if the name receives an affix beginning with a hard consonant. Thus, Amráotí, Amrávatí, Amráwatí (Amrauti), and Amrábatí are used in adjoining provinces for the same place Again the vowel *i* lengthens out into *e*, *ai*, *y*, and *aya*, and indeed the insertion or rejection of the liquid *y* forms a constant subject of discussion with the transliterator, and a fruitful

* Its other name is *Sadiya*.

source of irregularities in his work. Thus, to take only two instances. The Bengali loves to change *i* into *y* when it follows a consonant and is followed by a vowel; and to insert *y* after an *i* which would otherwise be followed immediately by a vowel. Thus, the word which in Urdu would be written Ulabáriá becomes in Bengali Ulabáriyá, and Sadiá becomes Sadiyá. Again the sound represented by the diphthong *ai* in one character is represented by *aya* in another. Thus, Jaipur for Jayapur, Ráipur for Rayapur, Rámpaili for Rámpayali. The numerous nasal sounds also have a set of difficulties of their own.

Passing to terminal variations, we find ourselves in the midst of a new growth of entanglements. Besides the practice of the Bengali and Nágarí-descended languages to use a final *á* for the Urdu *ah*, the Támil and other Southern Vernaculars have a perplexing system of terminal vowels, which most other Indian languages would consider redundant. But it will suffice to take the two most common terminations of Indian geographical names, *viz.*, *grám*, village; and *pur*, city. The former appears as grám in Northern India; as gám in Bombay (*e. d.* Telegám); as gáon in Central India and the North-West Provinces (as Gurgáon, Argáon and Waigáon); as gánw or gáno in Central and Southern India; and as gan (pronounced *gáng*, the final letter being the Chandrabindhu nasal) in Lower Bengal. I have attempted to assign localities to the different forms, but in practice they are intermingled throughout India, besides the variations introduced by English writers, as *gaum* (Belgaum), *gong* (Nowgong), &c.

The termination *pur*, city, is written with a long *ú*, *púr*, in Urdu; with a short *u*, *pur*, in Bengali; and either with a long or short *u* in Sanskrit and some of its descended languages. It also takes the feminine form *puri*, and in Southern India it becomes *puru*; besides several Anglo-Indian forms such as *pore* and *poor*.

Cases constantly occur, therefore, in which the transliterator has to decide between the uniform philological spelling of the word and its conflicting local variations. With regard to *gram*, I have found it necessary to follow local usage, so that it appears in the following list as *grám*, *gáon*, *gám*, and *gán*. With regard to the second great terminal affix, *pur*, I have uniformly spelt it with a short *u*, as *pur*. A third common affix, *nagar* town, which Anglo-Indians have hitherto variably spelt as *nagar*, *nagore*, *naggur*, *nuggur*, *nuggore*, &c., is here uniformly spelt *nagar*. A fourth, *shahr*, city, has enjoyed an even wider range of orthography, but is here invariably spelt *shahr*. In the same way, *ábád*, a cultivated or inhabited place, hence a town, appears uniformly as *abad*, without the accents, which in nine words are not needed to assist the English reader to pronounce this affix, and which are very inconvenient in the practical construction of the maps. This also applies to the termination *bázár*, which for the same reason I render as *bazar*, without the accents.

Throughout the whole list I have endeavoured as much as possible to get rid of accents. Such little marks greatly increase the difficulties of accurate printing and map-making, and the English eye is unaccustomed to them. An inspection of any page will show how far I have gone in this respect. On the one hand, the Surveyor-General and other authorities have pressed on me the necessity of reducing the number of these marks to a minimum; on the other hand, I have endeavoured in every case to retain a sufficient number of accents to show the true pronunciation at a glance. Thus, I have eliminated all accents on the long final *á* in the Nágari-descended languages; and it must be remembered that this final *á* represents the final *ah* in a vast class of Urdu words. Again, I have seldom attempted to distinguish between the long *í* and *ú*, and the short *i* and *u*; for the very simple reason that even the natives of India seldom make a distinction between the long and short sounds except in reciting poetry. When I accent an *i* or *u*, I do so to assist the English reader in pronouncing the word, and not for any philological reason. Thus, in *Púdi*, I accent the *u* to counteract the natural tendency of the English reader to pronounce it *Páddy*. In the same way I have omitted the accent over the long *á* wherever I thought it could be safely done without leading to practical mispronunciation. Accents will be more freely used in the Gazetteers; the manual difficulties of typography being in this respect

much less than those of the map-maker. Such words as Muscat and other places outside of India, I have considered beyond my jurisdiction and left untouched.

Besides difficulties arising from dialectical variations, almost all of which are susceptible of philological explanation, there is a residue of local changes susceptible of no explanation whatever. Thus, while it is easy to explain and deal with the change of the Sanskrit *sinha*, lion, into the Urdu *singh*, it would be mere waste of time to speculate why the Assamese pronounce as Lakhimpur what the Bengalis pronounce as Lakhmipur (practically Lakhipur), and the inhabitants of Northern India as Lachhmipur. The two last forms are dialectical varieties of the Sanskrit Lakshmipur, but the Assamese Lakhimpur is merely a local corruption.

Any attempt, therefore, to introduce a uniform system of spelling for Indian geographical names has to encounter three great sources of difficulty. The first is the popular or historical fixity which such names may have obtained by frequent occurrence in Anglo-Indian literature. This, however, although it will cause the loudest opposition in the meanwhile, is of a temporary nature, and has only to be firmly faced in order to be overcome. The second proceeds from the dialectical variations which have taken place among the numerous descendants of the Sanskrit language, and of its Deva-Nágarí alphabet. In such cases the uniform principles of Indian philology pull one way, and local usage pulls another. It is doubtless a very great blemish in an alphabetical list that exactly the same name should occur in it under different forms. But, on the other hand, it would be fatal to represent a town under a form which the inhabitants of it would not themselves recognize. The third difficulty springs from arbitrary local usage, as in the case of the Assamese Lakhimpur, which I have been forced to adopt, notwithstanding the thousand Lakhmipurs which dot the very next province, *viz.*, Lower Bengal.

I therefore did not exaggerate at the beginning of this Note when I said, that a protracted, intricate discussion might be raised around every one of at least fourteen hundred names in the following list. I only beg that it may be believed that in every case I have carefully weighed all the arguments which I conceive could be urged in favor of each of the possible modes; and that, after most careful consideration, I have adopted the one which, on the whole, seemed to me best.

Yet I cannot hope that in all cases my view will obtain the permanent sanction of popular use. In some cases my own judgment may have erred; in others, the vernacular lists, on which my decision has been based, may be at fault. I believe there is no instance in European history of the retention of a country's geographical names having been carried into execution by a single man on so large a scale. It is as if a scholar with a general knowledge of the Romance Languages, but practically unacquainted with several of their members, were to be asked to draw up a uniform spelling of all Europe, excepting Russia. One of the public journals lately stated that the English Government, before undertaking the Survey of Ireland, employed a Special Commission to ascertain the accurate orthography of Irish geographical names. Situated as we are in India, it is hopeless to expect to be able to use as complete or efficient machinery as the English Government can command. But this consideration will perhaps tend to excuse blemishes in a work which the great variety of the dialects, and the vast extent of the country, renders at least ten times more difficult; and which had to be executed by a single officer during such spare hours as he could devote to it after his regular Government work.

(Sd.) W. W. HUNTER,

Dir.-Genl. of Statistics to the Government of India.

SIMLA,
10th November 1871.

INTRODUCTORY NOTE BY THE SECRETARY TO THE PHILOLOGICAL COMMITTEE OF THE ASIATIC SOCIETY OF BENGAL.

On the Key to Professor H. H. Wilson's System of Transliteration.

THE following extract from the Proceedings of the Asiatic Society of Bengal for May 1867 will explain the object of this Key to Professor H. H. Wilson's system of transliteration:—

"The Council reported that they have adopted the following report of the Philological Committee, recommending to introduce the Jonesian system of transliteration in spelling Oriental names in the Society's Journal and Proceedings:—

"The Philological Committee of the Asiatic Society, having taken into consideration a proposition of Babu Rajendralala Mitra, referred to them by the Council, for the adoption of a uniform system for the Romanising of Oriental words in the Journal, beg to report that it is highly desirable that the system recommended—that of Sir William Jones, as modified by Professor H. H. Wilson—should be adopted.

"They are of opinion, however, that before enforcing it as regards contributions to the Journal, it would be well to print a Key to the system, and to circulate it for the information and use of contributors.

"As regards the linguistic vocabularies, the Committee recommend that those that have been already received should be returned to their authors, with a copy of the Key, to have them revised and put into one uniform system of spelling; and all further contributions of the kind should be treated in the same way.

"Copies of the Key should also be sent to Government, with a request that they may circulate them among those who have been called upon to co-operate in carrying out the proposed ethnological congress.

"Further, with a view to get the system generally adopted, the Council should place itself in communication with the Punjab and the Nagpur branches of the Society, as also with the Bombay and the Madras branches of the Royal Asiatic Society of Great Britain and Ireland, and ask their opinion and co-operation."

In carrying out this system of Romanising, the most important rules to be borne in mind are, *1st*, that "the vowels are to have the powers which they enjoy in most European languages, except English, and especially in Italian (as shown in the scheme); and, as in Latin, quantity is not to be represented by a difference in the letter, the long and short vowel being held to be one and the same letter, the former being distinguished by the acute accent in whatever part of the word it may occur," and not by a duplication of the letter.

2nd.—That in transcribing *written languages*, the spelling which is recognised by them as correct should be accepted without alteration, and the transliteration of such spelling in the Roman character should be determined in accordance with it, so that every Indian letter may always be represented by the same Roman equivalent, without any reference to the varying phonetic powers of the original or its equivalent under different circumstances.

For *unwritten languages* a purely phonetic system must necessarily be followed, and a letter or a combination of letters, as given in Professor Wilson's scheme (pp. 3 and 5), should be used for each distinct sound.

Should it be necessary to indicate any sound not included in the scheme, an appropriate Roman letter or combination of letters should be used, with such diacritical marks as may be deemed advisable, care being taken not to assign any new powers to the marks used in Professor Wilson's scheme. The peculiarity of all such new sounds should be explained in footnotes when they first occur. But it is to be remembered that "no new sound should ever be acknowledged as such, until we are able to give a clear and scientific definition of it on physiological grounds" (Max Müller), for it often happens that what appears at first hearing to be a new sound, turns out, on further experience, to be only an individual exceptional peculiarity, or the result of imperfect apprehension.

Two vowels coming together, but not uniting into a diphthong, should be separated by a hyphen; compound words should also be separated by hyphens.

R. M.

A KEY TO PROFESSOR H. H. WILSON'S MODIFICATION OF SIR W. JONES' SYSTEM OF TRANSLITERATION.

The Roman Alphabet adapted for Indian Languages.

			Sanskrit.	*Bengali.*	*Uriya.*	*Hindu-stáni.*
A	a	short as u in English b*u*t, =	अ	অ	ଅ	ا
Á	á	long as a in f*a*r, b*a*r, &c., ...	आ	আ	ଆ	آ
Â 'A*	â 'a	do. semi-vowel, ...	ा	—	—	ع
Ai	ai	gutturo-palatal diphthong, as in English aisle, or nearly as in German Kaiser, ...	ऐ	ঐ	ଐ	اي
Au	au	gutturo-labial, as ou in English lout or sound, or au in the German Haus, ...	औ	ঔ	ଔ	او
B	b	as in English, ...	ब	ব	ବ	ب
Bh	bh	nearly as in English abhor, ...	भ	ভ	ଭ	بھ
C	c	not to be used in transliteration.				
Ch	ch	as in church, ...	च	চ	ଚ	چ
Chh	chh	aspirated ch, ...	छ	ছ	ଛ	چھ
D	d	dental as th in English that, the, &c., ...	द	দ	ଦ	د
Dh	dh	aspirated d, ...	ध	ধ	ଧ	دھ
Ḍ	ḍ	lingual, as in English, ...	ड	ড	ଡ	ڈ
Ḍh	ḍh	aspirated English d, ...	ढ	ঢ	ଢ	ڈھ
E	e	long, as a in English pate, mate, &c., as the first e in German *e*del, or in French Lumière, or Italian Lumiera,	ए	এ ে	ଏ େ	ي
Ê	ê	short as e in bet, pet, men, &c.	—	—	—	—
F	f	as in English, ...				ف

* The alternative forms are not Wilson's. They are recommended as the diacritical marks attached to them can be produced with greater ease and saving of time, or are more convenient than those proposed by him.

G	g	always hard as in gone, ...	ग	গ	ଗ	گ
Gh	gh	aspirated g, ...	घ	ঘ	ଘ	گھ
G̣h	gh	deeply guttural gh, ...	—	—	—	غ
Ḥ H	ḥ h	as in English, ...	ह	হ	ହ	ه
H Ḥ	h ḥ	a deeply guttural h, ...	—	—	—	ح
Ḧ	ḧ	a soft flatus, ...	ः	ঃ	ଃ	—
I	i	short, as i in English hill, mill, &c., ...	इ	ই	ଇ	ا
Í	í	long, as the diphthongs in English meet, peel, leave, or in French qui,... ...	ई	ঈ	ଈ	ي
J	j	as in English, ...	ज	জ	ଜ	ج
Jh	jh	aspirated j, ...	झ	ঝ	ଝ	جھ
K	k	as in English, ...	क	ক	କ	ک
Ḳ	ḳ	very sharp guttural, ...	—	—	—	ق
Kh	kh	aspirated k, ...	—	—	—	کھ
Ḳh	ḳh	sharp aspirated guttural, ...	ख	খ	ଖ	خ
L	l	as in English, ...	ल	ল	ଲ	ل
M	m	as in English, ...	म	ম	ମ	م
N	n	as in English, ...	न	ন	ନ	ن
Ṇ	ṇ	a cerebral n, ...	ण	ণ	ଣ	—
Ṇ̈ ń	ṇ̈ ń	as in English hang, bang, ...	ङ	ঙ	ଙ	—
Ṇ̈ n̲	ṇ̈ n̲	as in French Anjou, ...	ञ	ঞ	ଞ	—
N Ñ	ṇ ñ	nasal marks as n in the French bon, ...	ं	ঁ	ଂ	—
O	o	always long as in English mote, boat, pole, &c., ...	ओ	ও	ଓ	او - و
P	p	as in English, ...	प	প	ପ	پ
Ph	ph	aspirated p, ...	फ	ফ	ଫ	پھ
R	r	as in English, ...	र	র	ର	ر
Ṛ	ṛ	nearly as in English burr, ...	ड़	ড়	—	ڑ
Ṛi	ṛi	short lingual vowel, ...	ऋ	ঋ	ଋ	—
Ṛí	ṛí	long do., ...	ॠ	ৠ	ୠ	—
S	s	as in English, ...	स	স	ସ	س
Ṣ S'	ṣ s'	a palatal s, ...	श	শ	ଶ	—

S̤ Ç	s̤ ç	as in French ça, ...	—	—	—	ص
Ṣ S̱	ṣ s̱	a very sharp English s, ...	—	—	—	ث
Sh	sh	as in English sash, ...	ष	ষ	ଷ	ش
T	t	as t in French, Italian, German, &c., ...	त	ত	ତ	ت
Th	th	as th in English theory, theology, &c., ...	थ	থ	ଥ	تھ
Ṭ	ṭ	lingual, hard as in English trumpet, ...	ट	ট	ଟ	ٹ
Ṭh	ṭh	aspirated English t, ...	ठ	ঠ	ଠ	ٹھ
Ṭ̤	ṭ̤	a sharp French t, ...	—	—	—	ط
U	u	short, as in English full, push, put, (present tense), ...	उ	উ	ଉ	اُ و
Ú	ú	long, as in moot, rule, ...	ऊ	ঊ	ଊ	او - و
V	v	as in English;	व	ব	ଵ	و
W	w					
X	x	not to be used.				
Y	y	as in English, ...	य	য়	ୟ	ي
Z	z	as in English, ...	—	—	—	ز
Zh	zh	as j in French je, ...	—	—	—	ژ
Ẓ	ẓ	... ...	—	—	—	ذ
Z̤	z̤	... ...	—	—	—	ض
Z̤ Z̲	z̤ z̲	... ...	—	—	—	ظ

The Sanskrita and the Bengali Alphabets, with their Roman Equivalents.

Sanskrit.	Bengali.	English.	Sanskrit.	Bengali.	English.
क	ক	k	म	ম	m
ख	খ	kh	य	য	y
ग	গ	g	र	র	r
घ	ঘ	gh	ल	ল	l
ङ	ঙ	n̂	व	ব	v
च	চ	ch	श	শ	s′
छ	ছ	chh	ष	ষ	sh
ज	জ	j	स	স	s
झ	ঝ	jh	ह	হ	h
ञ	ঞ	n̤ n̠	अ	অ	a
ट	ট	ṭ	आ	আ	á
ठ	ঠ	ṭh	इ	ই	i
ड	ড	ḍ	ई	ঈ	í
ढ	ঢ	ḍh	उ	উ	u
ण	ণ	ṇ	ऊ	ঊ	ú
त	ত	t	ऋ	ঋ	ṛi
थ	থ	th	ॠ	ৠ	ṛí
द	দ	d	ऌ	ঌ	lṛi
ध	ধ	dh	ॡ	ৡ	lṛí
न	ন	n	ए	এ	e
प	প	p	ऐ	ঐ	ai
फ	ফ	ph	ओ	ও	o
ब	ব	b	औ	ঔ	au
भ	ভ	bh	ं	ং	ñ
			ः	ঃ	ʻh

Urdu, Persian, and Arabic, with their Roman Equivalents.

ا	a	ص	ç
آ	á	ض	z̤
اِ	i	ط	t̤
اُ	u	ظ	z̲
ب	b	ع	*
بھ	bh	غ	gh
پ	p	ف	f
پھ	ph	ق	ḳ
ت	t	ک	k
تھ	th	کھ	kh
ٹ	ṭ	گ	g
ٹھ	ṭh	گھ	gh
ث	s̲	ل	l
ج	j	م	m
جھ	jh	ن	n
چ	ch	و	v o u
چھ	chh	ه	h
ح	ḥ	ي	y i e
خ	ḳh		
د	d		
دھ	dh		
ڈ	ḍ		
ڈھ	ḍh		
ذ	ẓ		
ر	r		
ڑ	r̲		
ڑھ	r̲h		
ژ	zh		
س	s		
ش	sh		

* To be indicated by the vowel with which it may be associated with an apostrophe placed before it.

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